2014

Demand Side Management in India: Technology Assessment

INDIAN INSTITUTE OF TECHNOLOGY BOMBAY

SHAKTI
SUSTAINABLE ENERGY
FOUNDATION

DISCLAIMER

The Authors of this report have taken due care and caution in compilation of information from various sources including discussions with key stakeholders which it considers reliable and first hand. However, the authors do not guarantee the accuracy, adequacy or completeness of any information and are not responsible for errors or omissions or for the results obtained from the use of such information in this report.

The views and analyses represented in the documents do not necessarily reflect that of Shakti Sustainable Energy Foundation. The organization accepts no liability for the content of this document, or for the consequences of any actions taken on the basis of the information provided.

EXECUTIVE SUMMARY

Energy Efficiency and Demand Side Management (DSM) have significant potential in India. The need for affordable electricity and the energy and peak shortages make DSM important for India. Recognizing the importance of DSM to energy sustainability and carbon emission reductions, Indian Institute of Technology Bombay partnered with Shakti Sustainable Energy Foundation to initiate research for technology and landscape assessment of DSM programs and reviewed strategies being practiced in the country.

A stakeholder workshop was conducted at IIT Bombay in December, 2013, to identify the issues and barriers to DSM in the country followed by a training workshop at Lucknow in April 2014 as a capacity building initiative. During the April workshop, UPERC launched the DSM regulations in the state. These workshops helped in identifying the best practices in DSM and bringing together the experts practicing engineers and regulators.

The inputs obtained from distribution companies, utilities and regulators and a mapping of the technology assessment and landscape assessment for DSM has been completed and are presented at the National level workshop on Demand Side Management on 28th June 2014.

This report evaluates various the technology options for DSM in India.

Table of Contents

List of Tables

List of Figures

1. TECHNOLOGY ASSESSMENT FOR DEMAND SIDE MANAGEMENT IN INDIA

1.1 Introduction

Demand Side Management (DSM) usually is part of the least cost option of providing reliable and efficient energy services in Integrated Resource Planning[1] (IRP) and hence provides a cost effective substitute for power plants. The rationale for DSM can be justified when we weigh other load management or more precisely supply management alternatives from the perspective of the utility, customers and society.

The technology assessment report is structured to provide a comprehensive insight into the DSM technology segments (lighting, HVAC, refrigeration, cogeneration, etc.) that are deployed end-use wise across different power consuming sectors. Since there are various alternatives available within each of these end-use technology segments, a set of metrics are defined for each segment. This is to classify and assess the alternatives in order to get a comparative set of data for ease of deployment. Figure 1-1 provides the research methodology adopted in the report. *The "Why-What & How" model is used in order to understand the "Why" (the rationale for the report), decide the "What" (the content of the report) and plan the "How" (the steps used in structuring the report) in the context of the report.*

The objective of the report is to provide a detailed characterization of the DSM technology segments rather than that of all individual technology alternatives available within each segment. This will provide a resource for the DSM implementing agencies for selecting an appropriate technology that fits their DSM program requirements based on the targeted customer sector, and investment required.

Table 1-1 enumerates alternatives to DSM along with their merits and demerits with a view to present a balanced case for DSM while Table 1-2 presents the rationale for DSM by enumerating the advantages of DSM to utility, customers and society.

---

[1] Swisher J, Jannuzzi G &Redlinger R. Tools & Methods of Integrated Resource Planning (IRP) http://www.fem.unicamp.br/~jannuzzi/documents/IRPmanual.pdf

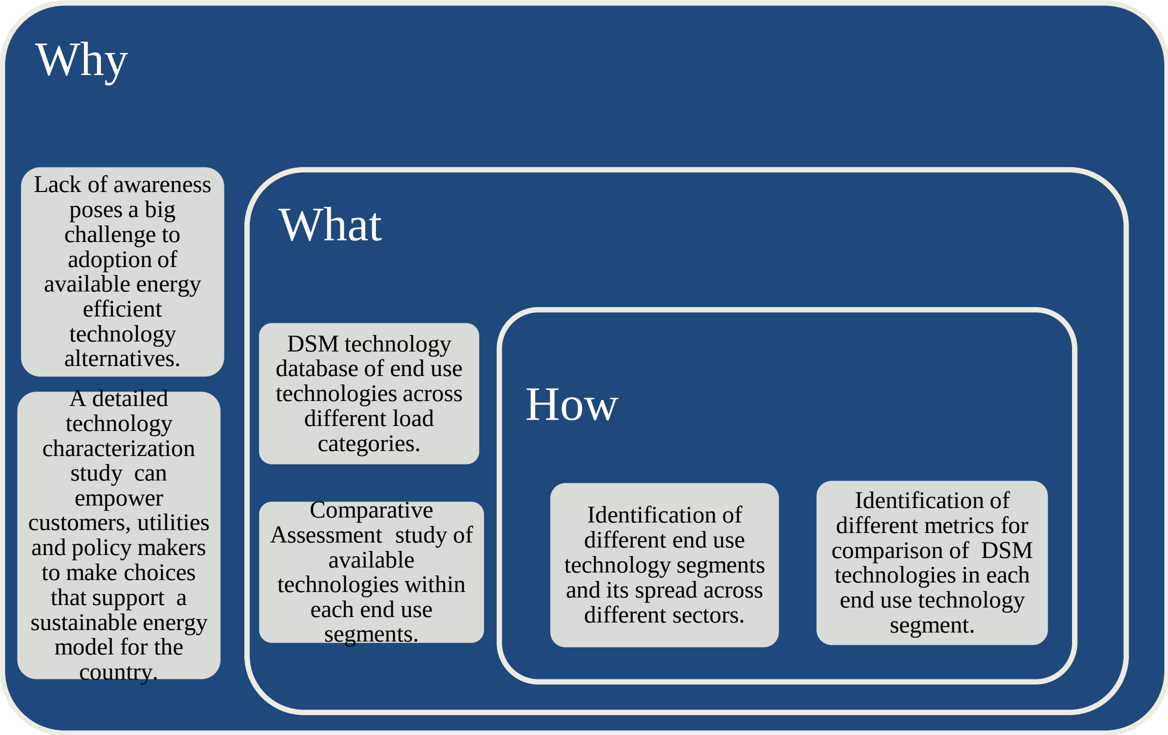

Figure 1-1 Research methodology for the technology assessment

Table 1-1 Alternatives to DSM - Merits and Demerits

Alternatives	Merits	Demerits
Renewable Source based Generation	• Sustainable • Requires less maintenance • Fuel available for free • Minimal adverse effect on environment due to less CO_2 emissions • Benefits of distributed generation	• Difficult to generate large quantity of power when compared to traditional fossil fuel generators • Reliability of supply • Capital cost of technology • Technology still in its nascent stage
Construction of fossil fuel based Power plants	• Provides capacity to generate huge amounts of electricity at just a single location	• Fuel intensive generation of power. • Carbon dioxide emission leading adverse environmental impacts
Peaking power plants (Gas and Pumped storage plants)	• Fast starts, stops and restarts, ensures perfect control load fluctuations during peak time.	• Expensive to install.
Rolling blackout or Load shedding	• Easiest and cost effective way to meet the surplus	• Unreliability in power supply. • Not a long term technique of load management

	energy demand • Protects the entire grid from cascading to a total blackout.	• Leads to discomfort of customers of all kind. • Loss of income

Table 1-2 Rationale for DSM – Perspective of Utility, customer and society

Utility	Customers	Society
Reduction in cost of operations due to avoided peak power purchase.	Reduced energy bills as the energy efficient equipment use less energy for the same level of output.	Reduced greenhouse gases emissions owing to avoided construction of fossil fuel based power plants.
Avoided capital expenditure on building new power plants, distribution and transmission networks.	Reliable power supply due to reduced power cuts and outages	Reduction in power outages enables equity in power distribution.
Improved customer satisfaction and operating efficiency.	Energy efficient appliances available at subsidized rates and through appliance exchange schemes	DSM promotes sustainable energy development through practice of resource optimisation of depleting fossil fuels & efficiency in energy conversion.
-	Reduced operation and maintenance cost as energy efficient appliances tend to have longer life.	-

The DSM initiatives can be divided into two major categories:

- Initiatives that bridge energy supply-demand gap through energy efficiency programs.
- Initiative which calls for voluntary response of customers to curtail their demand when asked by participating in demand response measures.

DSM can enable the energy users to act as virtual power plants[2] and power the utilities and grid operators to treat this virtual capacity as dispatchable resource to be called upon when needed through demand response measures. Dispatchable demand response measures can be customized for a commercial, institutional and industrial facility and can include turning off lighting, air conditioning, pumps, and other non-essential equipment without affecting business operations, comfort, or product quality.

---

[2] Gupta S, Bhattacharya T. DSM Power Plant in India. Renewable and Sustainable Energy Reviews (2013), http://www.teriin.org/projects/nfa/pdf/DSM_power_plant.pdf

DSM also incorporates measures that aim at promoting the installation and use of energy efficient end-use equipment that consume less power without any decrease in the quality of output. There is a need to view energy efficiency as a ‘resource option’, just like coal, oil, or natural gas for a sustainable future. For a developing country such as India, it provides additional economic value by preserving the resource base. In present scenario, energy efficiency assumes even greater significance because it is the most cost effective and reliable means of mitigating global climate change. Identification of potential for energy efficiency in energy intensive equipment and processes can open vast reserves of savings in terms of cost and available renewable resources. This will also lead to control of future carbon dioxide emissions and hence sustainable economic development.

Table 1-3 along with Figure 1-2 shows the sector wise electrical energy consumption share of different sectors in the country. The current peak demand shortage is 14% and the energy deficit is about 8.4%. In such scenarios, efficient use of electricity necessitates persistent energy conservation efforts through reduction in energy usage in a specific product without affecting output or user comfort levels.

Table 1-3 Sector-wise Energy consumption share[3]

Sector	Energy consumption	
	TWh	%
Industrial	1604.71	43.62
Residential and Commercial	505.09	13.73
Agriculture	269.12	7.32
Others	1299.54	35.33
Total	3678.46	100

---

[3] TERI Energy Data Directory Yearbook (TEDDY), 2011-12.

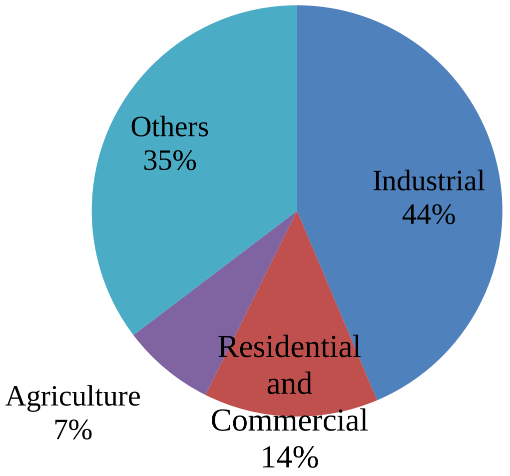

Figure 1-2 Energy consumption share in different sectors

1.2. DSM Technology Overview

Sector and End-Use Technology Mapping

It is imperative to identify the spread of end-use DSM technologies across the different load categories in order to develop the framework for assessing these technologies using appropriate metrics. These end-use technology segments, spread across different load categories, comprises of lighting, ceiling fans, refrigerators, HVAC, cogeneration systems, motor driven equipment, water heaters and Demand Response as shown in Table 1-4 and Figure 1-3. Each of these end-use segments has a number of technology variants (for example lighting has CFL, LED, FTL,etc). These technologies differ from each other in several parameters viz., efficacy, wattage, cost, colour rendering index etc. and also based on application.

Table 1-4 Sector Vs End-use Technology Options for DSM

	Residential	Industrial	Commercial	Agriculture	Municipal
Lighting	+	+	+		+
Ceiling Fans	+				
Refrigeration	+	+			
Air-conditioning	+	+	+		
Motor Driven Systems		+		+	+
Demand Response	+	+	+		+
Cogeneration		+			
Water Heating	+		+		

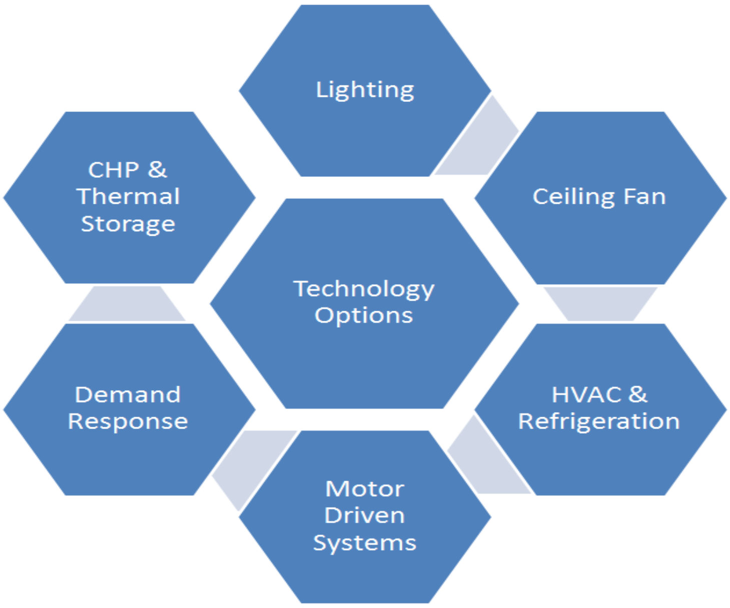

Figure 1-3 End-Use Technology Options for DSM in India

The following sections in the technology assessment report cover detailed analysis of the above mentioned end-use segments while assessing the cost effectiveness of the technology variants available within each of these end-use load categories using standard metric (cost of saved energy).

1.3 Lighting

From primitive ages, lighting is an essential requirement for people in their daily needs. Lighting consumes a minimum of 5 to 15% of total energy consumption for residential users and 30% for commercial users, and these values increases with the end user requirements. In certain small and medium retail business models, lighting accounts for 80% of total energy usage.

Table 1-5 shows the % contribution of different sectors in the total electricity consumption in the country with the % share of lighting component in that contribution. Lighting component for some manufacturing and processing industrial sectors can be 15% of industry's total electricity consumption. Similarly, for IT sector, which comes under commercial sector, lighting could account to 40 % or more in total electricity consumption.

Table 1-5 Lighting component in total electricity used for major economic sectors

Sector	Electricity used (% of total)	Lighting Component (% of total electricity used)
Industry	49	4-5
Commercial/Public	17	4-5
Domestic	10	50-90
Others	24	2

As per the 18th Electric Power Survey of CEA, the estimated energy consumption in Indian public lighting sector with 2009-10 as the base year is about 8478 million kWh in 2012-13. This sector is expected to grow at 7% annually during the XII and XIII plan periods. This trend is shown in Figure 1-4.

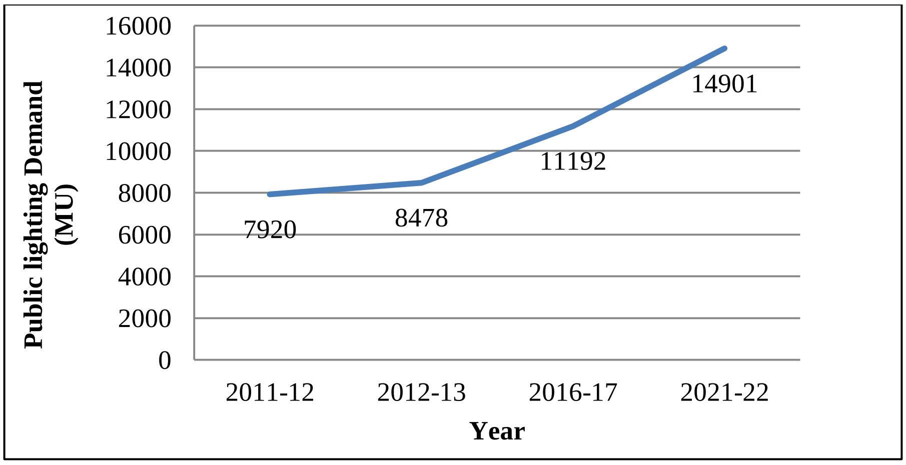

Figure 1-4 Growth in Public lighting demand over the coming years

As per BEE estimates, there are over 400 million lighting points in India using incandescent lamps which if replaced with CFLs would reduce approximately 6000-10000 MW and if replaced by LEDs would reduce about 10000-15000 MW of the electricity demand[4]. India's installed capacity of power generation is about 232,164 MW[5] and peak demand deficit is currently around 9 %. This means that with proper deployment of energy efficient lighting technologies, a significant capital investment can be avoided. Combined GHG emission savings on replacing an estimated 400 million ICLs with CFLs would also result in reducing about 20 million tonnes of (CO_2) from grid-connected power plants.

The large contribution of (domestic, commercial and street) lighting demand to peak load also makes it attractive for the utility to offer incentives for the adoption of efficient lighting practices by consumers. This would result in reduction of costly peak-load power procurement. With improvement in LED technologies, the lighting sector as a whole has immense potential to pursue energy efficiency options.

Moreover, strategies for conserving energy in lighting loads will require both technology and design expertise. Use of energy efficient lamps should be complemented with appropriate

---

[4] http://bee-dsm.in/PoliciesRegulations_1_4.aspx

[5] Executive summary of power sector, Nov 2013, Central Electricity Authority. http://www.cea.nic.in/reports/monthly/executive_rep/nov13.pdf

lighting design for a specific installation point or facility in order to meet the energy conservation goals.

1.3.1 Technology Options

There are three broad categories of lighting based on the physics involved i.e., incandescent, gas discharge and solid state lighting. The technologies used for general lighting purposes in indoor and outdoor locations are classified as shown in Figure 1-5.

Technology Comparison and Assessment

The choice of cost effective lighting technology that also scores well on the parameter of energy efficiency requires a comparative data that assesses the different options on a set of metrics. Table 1-6 gives detailed comparison of various technology options in lighting with different metrics. Considering the range of application areas and operating conditions, the choice of energy efficient lamp need metrics such as CRI (Colour Rendering index), Cost, warm-up and re-strike time, heat generated by lamps and lumen depreciation rate, for comparison with existing lamps used for general lighting purposes. Some definitions for these metrics are given below:

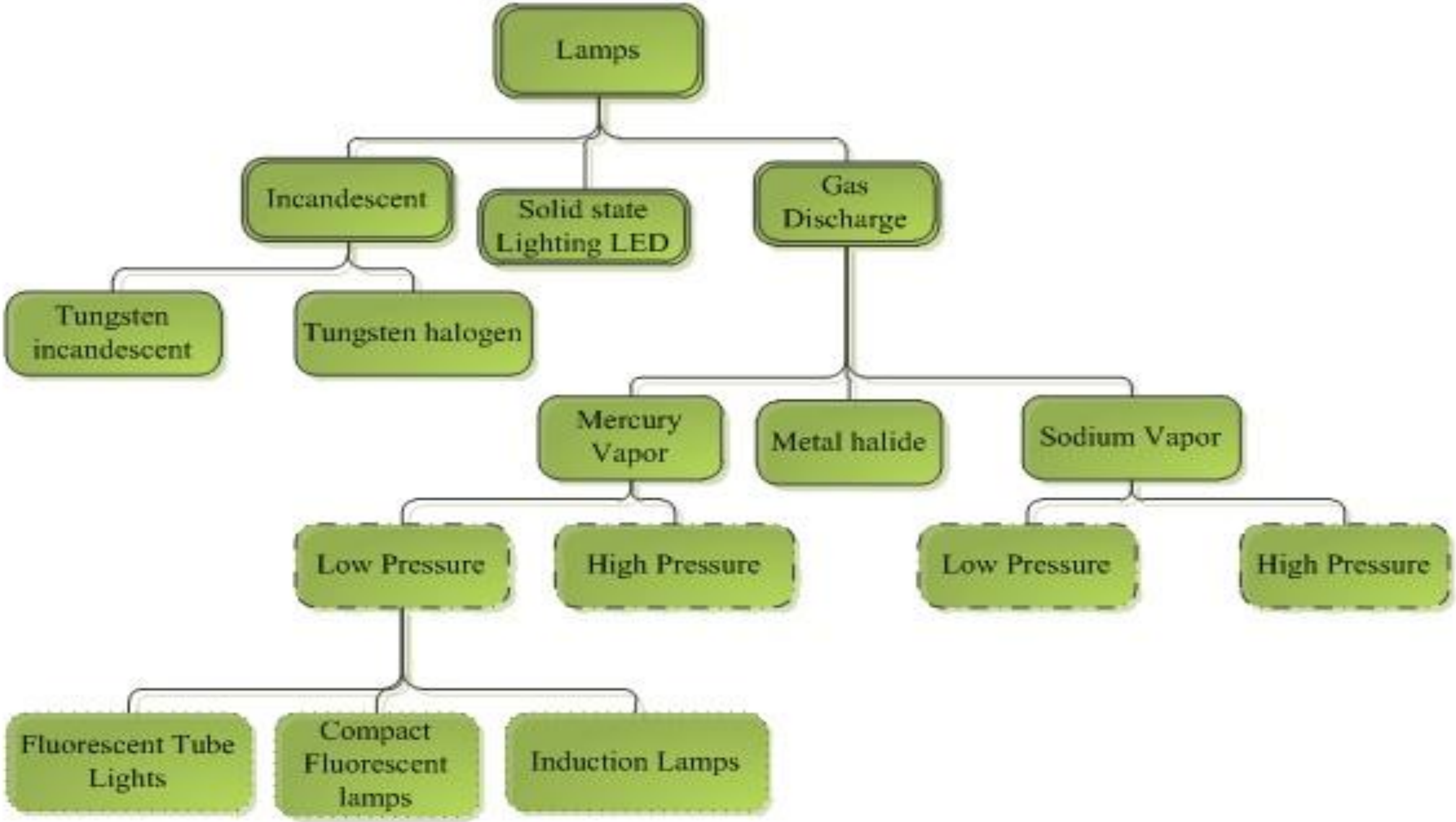

Figure 1-5 Types of lighting and their categories

Colour Rendering Index: It is a quantitative measure of the ability of a light source to reproduce the colours of various objects faithfully in comparison with an ideal or natural light source.

Efficacy: Luminous efficacy is a measure of how well a light source produces visible light. It is the ratio of luminous flux to power.

Table 1-7 shows the comparative assessment of the available lighting options for domestic sector. The lamp efficacy is the ratio of light output in lumens to power input to lamps in watts. Over the years, development in lamp technology has led to improvements in efficacy of lamps. However, low efficacy lamps, such as incandescent bulbs, still constitute a major share of the lighting load. High efficacy gas discharge lamps with LED and Induction lamp, suitable for different types of application, offer appreciable scope for energy conservation.

Table 1-6 Summary of lighting sources and their characteristics

	Light Source	Power Rating	Efficacy (Inclusive of Ballast loss)		Life Span (Avg.)	CRI	Correlated Colour Temp.	Lumen Depreciation Rate	Cost/Unit (without Ballast)	Warm up& Re strike	Application Areas
		Watt	**Lumens / Watt**		**Hrs**	**Base 100**	**Kelvin**	-	Rs.	Time (Minutes)	-
			Range	**Avg.**							
1	**Tungsten Incandescent (GSL / ICL)**	25-300	8-18	14	1000 - 1600	100	2700 (Warm)	10 to 15 % at 1000 Hrs	13 (60 W)	0	Homes, Restaurant, General & emergency Lighting
2	**Tungsten Halogen**	40-600	10-30	20	2000 - 5000	100	2800 - 3200	5 % at 2000Hrs	55 (150 W)		Automobile headlamps, Flood lighting, & Homes.
3	**FTL (T5,T8,T12)**	8-300	35-104	67	8000 - 16000	50-98	2700 - 6500	5 to 10 % at 16000 Hrs	150 (28 W, T5)		Offices, Shops, Hospitals & Homes.
4	**CFL**	6-42	33-65	50	8000 - 20000	76-82		20% at 10000 Hrs	150 (14 W)	0	Hotels, Shops, Homes, & Offices
5	**Induction Lamp**	23-165	64-73	70	60000 - 100000	90		5% at 2000 Hrs	8000 (40W)		Tunnels, Roadways, Cold storage lighting, Warehouses & Industrial buildings.
6	**LED**	4-28	60-140	100	50000- 60000	70-95	2800- 4000	30% at 30000 Hrs	990 (5W)	0	Homes, Shops, Hotels, Offices
7	**HPMV Lamp**	50- 1,000	32-60	50	15000 - 24000	40-60	3000 - 4000	20% at5000 Hrs	155 (125W)	4-6 10-15	Factories, Garages, Car parking, Flood lighting.
8	**HPSV Lamp**	70- 1,000	70-120	95	12000 - 32000	23-25	1900 - 2100		250 (70W)	10 1	Factories, Warehouses, street lighting.
9	**LPSV Lamp**	10-180	150	15	16000	15	Below 2000		-	10 3	Roadways &Industrial lighting
10	**Metal Halide Lamp**	50- 2,000	65-120	92	6000- 36000	60-90+	3000 - 6000	30% at 15000 Hrs	750 (70W, Quartz, single ended)	2-3 **10-20**	Outdoor lighting, Automobile headlamps,& Photographic and Stage lighting.

Table 1-7 Technology options for Domestic lighting

Domestic Lighting
Technology Comparison Matrix

Metrics for Comparison	***Unit***	**ICL**	**CFL**	**T12**	**T8**	**T5**	**LED**
Power Rating	*Watt*	60	14-15	34	32	21	6-8
Cost	*Rs.*	15	220	40	48	140	550
Initial Luminous flux	*Lumens*	840	900	2400	2800	2100	700
Lumen depreciation Rate	*%*	10 % at 1000 hrs	20% at 10,000	5-10 % at 20000	5-10 % at 20000	5-10 % at 20000	30% at 30,000
CRI	*Base 100*	100	82	62	78	85	70
Life	*hrs*	1000	10000	20000	25000	24000	50,000

Energy efficient options in lighting for various sectors are given in Table 1-8. The savings associated with choice of lighting technology are shown. Based on the time of usage one can calculate the savings in terms of energy.

Table 1-8 Energy efficient replacement options for lighting across different sectors

Sector	**Lamp Type**		**Power Savings**	
	Existing	**Proposed**	**Watts**	**%**
Domestic	GLS (60 W)	CFL (14W)	46	77
	T12 (40W) Magnetic ballast	T8 (32W) electronic Ballast	8	20
Industry	HPMV (250 W)	HPSV(150 W)	100	40
	Halogen lamp (500 W)	Metal Halide (150 W)	150	37.5
	HPSV (250 W)	Induction lamp (200 W)	50	20
Commercial	T12 with Magnetic ballast (40 W)	T5 With Electronic Ballast (28W)	12	30
	T12 with Magnetic Ballast (40 W)	T8 Electronic Ballast (32 W)	8	20
	CFL(36W)	LED lamp(23W)	13	36
Street Lighting	HPSV(250 W)	LED(150 W)	100	40
	HPSV (250W)	Induction lamp (200 W)	50	20

Case Study:

In this case study, the annual cost of saved energy is calculated when an energy efficient technology is replacing existing (conventional) one. In the present case, replacement of ICL with CFL and LED is illustrated. Table 1-9 gives the input data required for the analysis. The discount rate for utility, society and consumers is assumed to be 10%, 15% and 20-20% respectively.

Table 1-9 Calculation of Cost of Saved Energy (CSE) for energy efficient lighting replacements at different discount rates

Metrics for Comparison	Unit	GLS	CFL	LED
Luminous Efficacy	Lumens/watt	12	50	120
Rated Wattage	Watt	60	14	6
Luminous flux	Lumens	800	700	720
Cost/unit	Rs.	15	150	1200
Life of Technology	Hours	1000	8000	30000
Life of Technology (n)	Years	0.303	2.42	9.09
Operating Hours per Day	Hrs	10	10	10
Operating Day per Year	Days	330	330	330
Cost of Power	Rs/kWh	5	5	5

The annualized capital cost of energy efficient option and standard option are given by (1) and (2) respectively.

$$(\mathrm{ACC_{EE}}) = CC \times CRF \tag{1}$$

$$(\mathrm{ACC_{Std}}) = CC \times CRF \tag{2}$$

In eq. (1) and (2), CC is the effective capital cost for energy efficient option and CRF is the Capital Recovery Factor defined as in (3).

$$\mathrm{CRF} = \frac{\mathrm{d}(1+\mathrm{d})^{\mathrm{n}}}{(1+\mathrm{d})^{\mathrm{n}} - 1} \tag{3}$$

Where, **d** is the discount rate and **n** is the life of the energy efficient technology. The cost of saved energy is given by (4):

$$\text{Cost of saved energy} = \frac{ACC_{EE} - ACC_{Std}}{Annual\ energy\ savings} \tag{4}$$

The cost of saved energy is a statistic used to compare energy conservation measure among them and with the existing cost of energy. An energy-efficient measure is considered to be cost effective when the cost of saved energy is less than cost of electricity. The discount rate represents the scarcity of capital. Higher the discount rate higher is the scarcity of capital or lesser is the availability of funds to invest in energy efficient technology.

Option 1: Replacement of ICL with CFL

Replacement of ICL with CFL is most popular DSM technique in India. This has also passed the benefit and cost analysis tests. The cost of saved energy by replacing ICL with CFL is calculated for various working hours and discount rates. The results are plotted in Figure 1-6. It can be seen that with increase in working hours (usage) of the energy efficient equipment, the cost of saved energy decreases and hence makes the technology option viable, in the present case it is replacement of ICL with CFL.

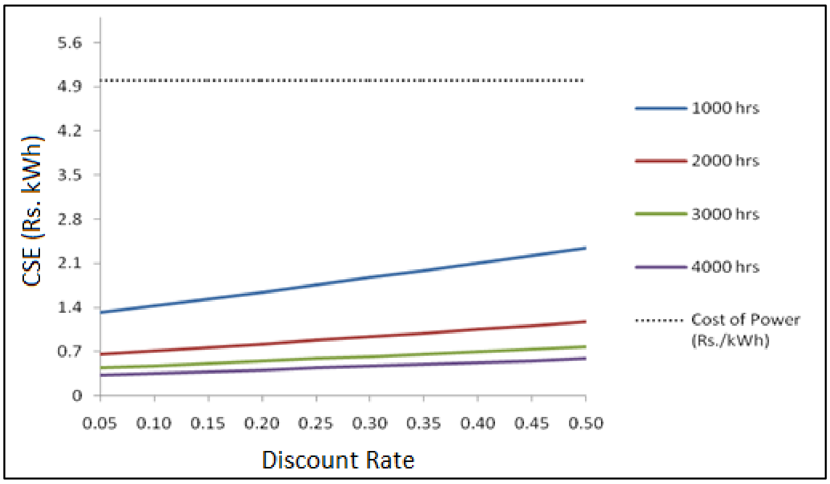

Figure 1-6 Variation of cost of saved energy with discount rate and hours of operation (GLS vs. CFL).

Option 2: Replacement of CFL with LED

Now-a-days LEDs are becoming popular in domestic sector and are seen as future replacement of CFLs. In this context, analysis of cost of saved energy for replacement of CFL with LED for various discount rates and usage hours is done using (1) to (4) and the results are plotted in Figure 1-7. It can be seen that the cost of saved energy is higher for case with higher discount rate and low working hours, in such cases replacement of CFL with LED is unviable. However, with LED technology promising working hours of 50,000 (approximately) this situation may not arise. It can be seen from Figure 1-6 that for high working hours (>5000) LED is going to be a good choice (for a discount band of 10-50%).It is also clear from the figure that investment in energy efficient technology becomes more cost effective with increase in the hours of operation for the same investor or stakeholders with same discount rate.

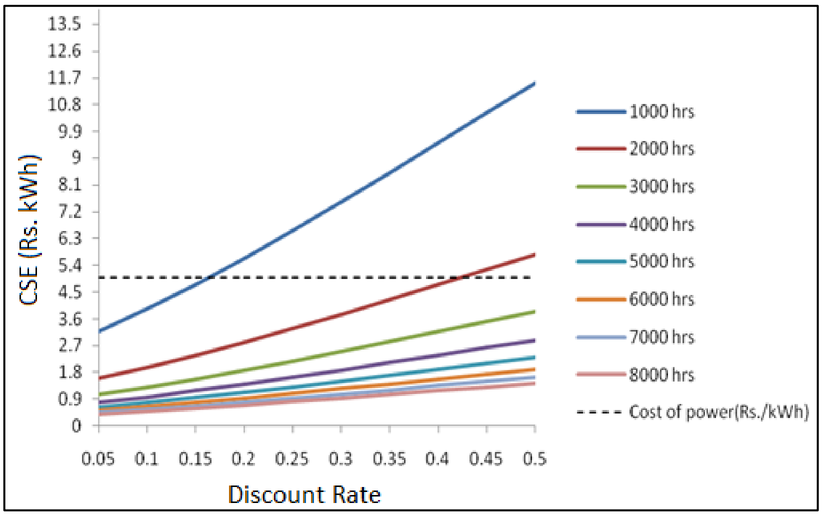

Figure 1-7 Variation of cost of saved energy with discount rate and hours of operation (CFL vs. LED)

Energy efficient measures need to be implemented by agencies that have a lower discount rate. When the market penetration is increased (with time) owing to reduction in the price of energy efficient technology and awareness, such measures will automatically become cost effective to implement for consumers with relatively higher discount rate. LED Village campaign project by BEE, covering 27 villages across the country are efforts in this direction.

Control Gear:

In addition to choice of technology, the control gear plays a very important role in reduction of the overall power consumption by the device. It is also possible to reduce the energy consumption in these lighting technologies by using advanced energy management systems like dimming. Control gear in a lighting unit consists of electrical or electronic components which includes ballast, power factor correction capacitor and starter. To allow the facilities like dimming, some high-frequency electronic control gear components are also present. Some widely used industrial lighting control gears are explained below:

1. **Electronic and magnetic ballasts for fluorescent and HID lamps:** The ballast provides a high initial voltage to initiate the discharge, and then rapidly limits the lamp

current to safely sustain the discharge. The features of electronic and magnetic ballast that are used with FTLs and HID lamps are compared in Table 1-10.

Table 1-10 Comparison between Magnetic and electronic ballasts

Indices for comparison	Magnetic ballasts	Electronic ballasts
Noise level	*High*	Low
Flicker index	0.04 – 0.07	< 0.01
Starting Mode[6]	PH,IS,RS	IS,RS,PS
Weight (kg)	1.58	0.18
Operating Frequency (Hz)	50	20,000 to 60,000
Dimming available	Yes	Yes
THD (%)	*Mostly <20*	Mostly 5-20
Power Factor	Mostly >0.9	>0.9
System Efficacy	lowest	Highest
Ballast factor	0.63-0.99	0.73-1.30
Loss/lamp (Watt)	14-15	1-2
Heat dissipation	High	Low

2. **Electronic and magnetic transformers for Low Voltage Tungsten halogen lamps:** Transformers are used as power supply units to reduce the voltage of mains electricity supply (220V) to a lower voltage of 12 V AC, for operating low voltage tungsten halogen lamps. These halogen transformers can be either magnetic or electronic.
   Electronic transformers are smaller and lighter than magnetic transformers, and often include output voltage regulation with lamp protection circuitry, soft starting, etc.
   Losses occurring at full load represent the majority of losses. These losses vary between 3W and16W per transformer for 50-60VA magnetic transformer. Electronic units of this size generally have losses of around 4W, while a typical magnetic transformer has losses of around 14W.

3. **Constant current and constant voltage drivers for LED lamps:** Constant voltage drivers are used with LED lamps when it is installed in sign boards. It provides a fixed voltage, often 12VDC or 24VDC and the current is usually regulated by either resistors that have been wired in series with the LEDs or by an onboard built-in regulator driver that the LED module may have.
   Constant current drivers fix the current, by varying the input voltage. Higher output voltage is set by the driver, till maximum voltage, for increase in number of LEDs connected across the driver.

---

[6] PF=Pre Heat, IS=Instant-Start, RS=Rapid-Start, PS=Programmed Start.
http://www.lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SREB2.pdf

4. **Dimming controllers for lamps with external ballast:** Lamps with integrated ballast (such as screw base CFL) cannot be dimmed or brightened because the component responsible for light control is integrated within the ballast. But some lamps come with electronic ballast having dimmable controller that enables a lamp to be dimmed or brightened as per requirement. A photocell which detects daylight is attached to this gear for automatic dimming when daylight is detected. This kind of effective light and energy management leads to additional energy savings.

5. **Occupancy Sensors:** Occupancy sensors are used to detect human presence so as to control the switching on and off of lamps according. Infrared (IR) and Ultrasonic occupancy sensors can be used to control lighting in cabins, large offices and toilets in buildings. Some occupancy sensors have a combination of both IR and ultrasonic for detection. A programmable microprocessor in each unit which continuously memorizes the changing features of the environment and monitors the sensors to adjusts their sensitivity levels to optimize the performance. This ensures the cancellations of false signals from repetitive motion equipment like fans.

1.4 Ceiling Fan

Ceiling fans are the most common electric appliance in Indian households and offices after electric lamps, consuming about 20% of the electricity in the domestic sector. According to the survey conducted by Prayas Energy group[7], the domestic sales for ceiling fans in 2008-09 was about 27 million and the growth in sales being 12%. The survey also mentions that, about 70% of the fans in 2020 will have been added after 2009. This needs market transformation and product awareness measures to increase the penetration rate of energy efficient ceiling fans in the market. The technologies options available for ceiling fan category are,

- Ceiling fans with single phase induction motor
- Ceiling fans with Brushless DC motor[8] (also called super energy efficient fan)

---

[7] Report on “Ceiling Fans: The Overlooked Appliance” by Prayas energy group, Available online at http://www.prayaspune.org/peg/publications/item/81.html

[8] BLDC fans in India. Executive Summary available at: http://www.superefficient.org/en/Activities/Technical%20Analysis/~/media/Files/SEAD%20Technical%20Analysis%20Reports/SEAD%20Ceiling%20Fan%20Analysis/SEAD%20Ceiling%20Fans%20Report%20Executive%20Summary.pdf

- High Volume Low Speed (HVLS) fans

Among the above mentioned technologies, single phase induction motor based ceiling fan is the most widely used technology. Thus, replacing ordinary fans with energy efficient ones will greatly improves the overall system efficiency. The following case study shows the cost of saved energy in case of technology switching in the context of ceiling fans.

Case Study:

The cost of saved energy is a statistic measure to compare cost of energy savings among energy efficient technologies and the existing inefficient technologies. An energy-efficient measure is considered to be cost effective when the cost of saved energy is less than cost of electricity. The discount rate represents the scarcity of capital. Higher the discount rate higher is the scarcity of capital or lesser is the availability of funds to invest in energy efficient technology.

Option 1: Replacement of Standard Ceiling Fan with 5 Star rated Ceiling Fan

In this case study, the cost of saved energy is calculated when an energy efficient technology is replacing existing (Standard Ceiling fan) energy intensive appliance. In the present case, replacement of standard fan with energy efficient 5 Star rated ceiling fans. The discount rate for utility, society and consumers is assumed to be 10%, 15% and 20-30% respectively. Annual energy cost savings are calculated using the date given in Table 1-11 for replacement of standard ceiling fans with 5 Star rated fan. The estimated savings clearly shows the potential and reason for the use of energy efficient ceiling fans in place of standard ceiling fan.

Table 1-11 Calculation of annual energy cost savings for available alternatives to standard ceiling fan

Indices for Comparison	Standard Ceiling Fan	5 Star Rated Fan (BEE)	Super Energy Efficient Fan (BLDC motor)
Power(Watt)	75	50	35
Span (mm)	1200	1200	1200
Speed (rpm)	400	350	350
Air Delivery (m^3/Min)	235	225	230
Cost/Unit (Rs.)	1400	1900	2600
Annual energy consumption(kWh)	247.50	165	115.50
Annual Energy Cost Savings (Rs.)	-	82.50	132.00

The cost of saved energy by replacing conventional fan with the 5Star rated ceiling fanis calculated for various working hours and discount rates. The results are plotted in ure 1-8. It can be seen that with increase in working hours (usage) of the energy efficient equipment, the cost of saved energy decreases and hence makes the technology option viable.

It is clear from Figure 3-8, that investment in energy efficient technology (5 star rated fans) becomes more cost effective with increase in the hours of operation for the same investor or stakeholders with same discount rate.

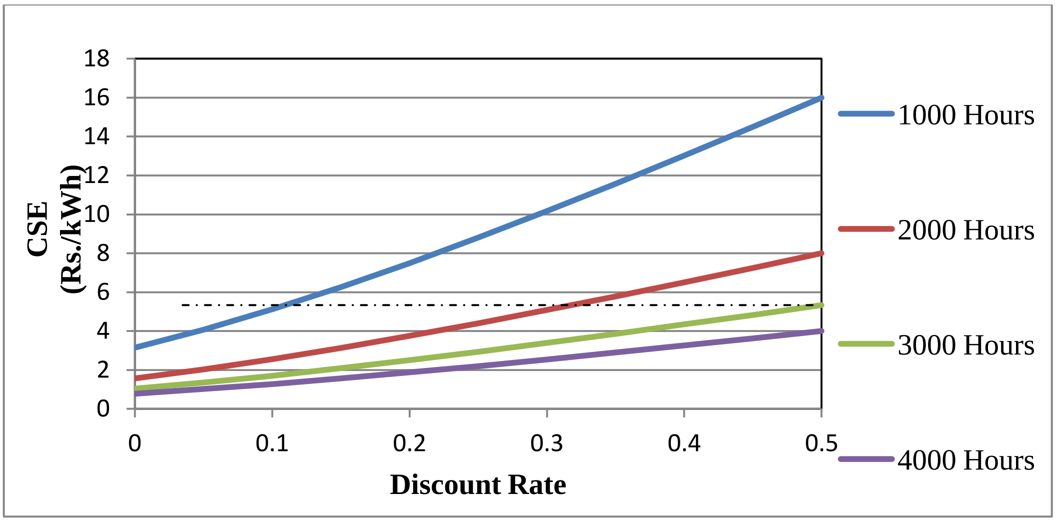

Figure 1-8 Comparison of cost of saved energy for various discount rates and hours of operation for standard ceiling fan versus 5 star rated fans.

Option 2: Replacement of Standard Ceiling Fan with Super energy efficient ceiling fan

Cost of saved energy is calculated using (1) to (4) and comes out to be lower than electricity tariff rate thus making the replacement measure cost-effective for all practical values of discount rate. Figure 1-9 shows the cost of saved energy variation for different discount rate for both replacement option 1 & 2.

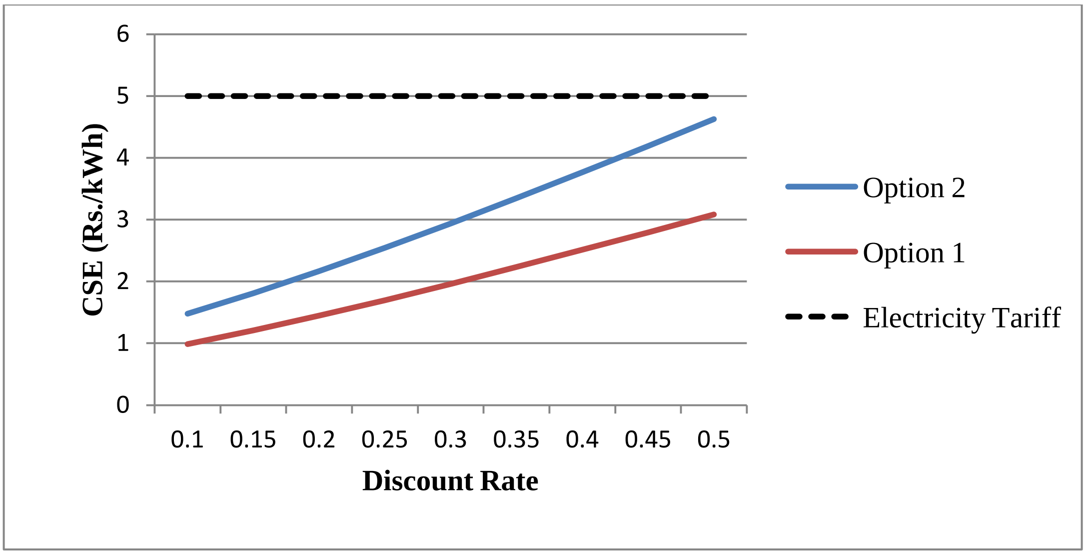

Figure 1-9 Comparison of cost of saved energy for options 1 and 2 with cost of electricity

1.5 Heating, Ventilation and Air conditioning (HVAC)

HVAC is a term used to represent the facility that maintains the ambient conditions as per the comfort criteria of the users. The main applications of HVAC can be found in,

- Residential areas
- Industrial processes
- Commercial buildings
- Goods storage

There following are main processes that come under HVAC category.

a) Heating : Raising the temperature of the targeted space to the desired level
b) Cooling : Decreasing the temperature of the targeted space to the desired level
c) Humidifying: Raising the moisture content in the targeted space to the desired level
d) Dehumidifying: Lowering the moisture in the targeted space to the desired level
e) Cleaning: Removing unwanted particles such as dust from the targeted space.
f) Air movement and Ventilating: Providing ventilation to the targeted space to maintain freshness.

In general, HVAC systems can be characterized based on type of space to be conditioned as, Single Zoned Systems (for single targeted space) and Multi Zoned Systems (for multiple targeted spaces with different requirements).The usage of HVAC is decided by the climatic zone in which the installation area falls. Table 1-12 shows the various climatic zones in India with the respective HVAC requirements.

Table 1-12 Type of HVAC requirements across various climatic zones in India

S. No.	Climatic Zones	City	Type of HVAC load
1	Hot & Dry	Jodhpur	High Cooling
2	Warm & Humid	Mumbai	Ventilation
3	Moderate	Bangalore	Lighting
4	Cold & Cloudy	Shimla	Medium Cooling, Heating & lighting
5	Cold & Sunny	Leh	High Heating
6	Composite	Delhi	High Cooling & Medium Heating

1.5.1 Technology Options in HVAC

The following are the HVAC technologies for majority of the applications.

Vapour Compression HVAC system[9]: In this type of HVAC systems, the heat is absorbed from the refrigerator and released into the targeted space. In large scale applications, these are used to cool water which is pumped as coolant. The heat absorbed from the coolant is released into the atmosphere. Majority of the refrigeration refrigeration systems appliances such as household refrigerators work on the principle of vapour compression and expansion.

a) Figure 1-10shows the components in a HVAC unit that operates on vapour compression technology. Chillers along with air handling unit and working fluid (refrigerant) constitute a basic HVAC system. A chiller consists of a compressor, evaporator, condenser and an expansion device. Chillers are the energy intensive part a HVAC system. Choice of efficient chillers depends on the correct combination of type of compressor and condenser. Screw water cooled chillers are found to be more energy efficient than the reciprocating air cooled chillers. Screw compressors run at 100% duty cycle and operate at cooler temperatures for same rating as compared with reciprocating compressors. Air cooled condensers operate at higher condensing temperature than their water cooled counterparts thus requiring compressors of larger capacity which consume more power and are hence highly inefficient.

---

[9] CEP Course Material, “Energy Management” IIT Bombay, November 2013

b) **Vapour Absorption system**[10]: The waste heat expelled into the atmosphere by industrial process can be used to drive the heat driven refrigeration processes like absorption refrigeration. In these systems, the compressing unit of the vapour compression process is replaced by a heat compressor and a sorbent to produce the cooling effect.

c) **Heat Pump:** In HVAC applications, the notion of heat pump is used to represent the reversible vapour-compression systems that are designed to offer high efficiency in either directions of heat energy transfer. In general, heat flows impulsively from warmer areas to colder spaces. In case of heat pumps, the heat can be made to flow either direction from a cold space to a warmer one. This process is not energy conservative which implies it requires an external source of energy, such as electricity.

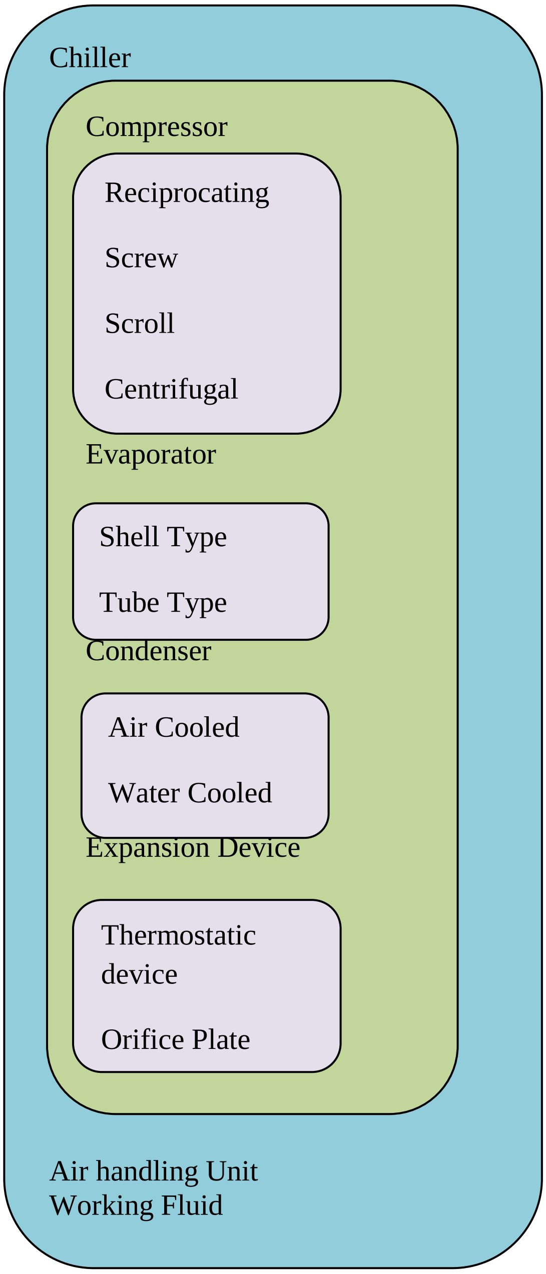

Figure 1-10 Components of a basic HVAC unit using vapour compression technology.

d) **Evaporative Cooling system:** Evaporative cooling systems are popular and energy efficient in regions with humidity less than 50% (dry climates). Hot outside air enters the cooler and passes over water, making water evaporate into air. This humidified air of 15 to 40 ºC, pushes warmer air outside the room through windows. These coolers

---

[10] P Srikhirin, S Aphornratana, S Chungpaibulpatana: A review of absorption refrigeration technologies. http://users.ntua.gr/rogdemma/A%20Review%20for%20Absorption%20Refrigeration%20Technologies.pdf

circulate fresh humid air, used in areas of low humid regions during summers and consume only one-third amount electricity than a normal air-conditioner do.

e) **Thermal Storage system:** Thermal storage system is a device that can stock thermal energy by cooling, heating, melting, solidifying or vaporizing a material. A thermal storage system is a useful device to reduce peak power reduction by storing energy during off peak hours for heating or cooling loads during peak hours.It can store energy either by non-chemical process like latent heat storage (involves phase changing material) called sensible heat storage or by a reversible chemical reaction process called thermo-chemical heat storage.

f) **Solar Thermal Cooling:** In solar thermal cooling, solar collectors (parabolic concentrators) capture heat from the sun and run a Vapour Absorption Cycle (VAC) to convert the captured heat to cooling. This cooling has potential to reduce the electricity load caused by conventional electric Air-Conditioning units during peak summers.

Case Study: Residential Air conditioners

In this case study, the annual cost of saved energy is calculated when an energy efficient technology is replacing existing (conventional) low star rating air conditioner in residential sector. In the present case, three replacement options are considered

Option 1: Replacement of 2 Star rated split AC with 3Star rated split AC

Option 2: Replacement of 2 Star rated split AC with 4Star rated split AC

Option 3: Replacement of 2 Star rated split AC with 5Star rated inverter AC

The cost of saved energy is a statistic used to compare energy conservation measure among them and with the existing cost of energy. An energy-efficient measure is considered to be cost effective when the cost of saved energy is less than cost of electricity. The discount rate represents the scarcity of capital. Higher the discount rate higher is the scarcity of capital or lesser is the availability of funds to invest in energy efficient technology.

Energy efficient options in air conditioners based on star rating are shown in Table 1-13. The savings associated with choice of star rating can easily be calculated from this table. Based on the time of usage one can calculate the savings in terms of energy. Now-a-days high star rating AC's are becoming popular in domestic sector along with 5 Star rated inverter split ACs. In this context, analysis of cost of saved energy for replacement of 2 Star split with 3Star, 4Star and 5 Star AC for various discount rates and usage hours is done using (1) to (5) and the results are plotted in Figure 1-11.

Option 1, which is replacement of 2 Star rated split AC with its 3 Star rated counterpart is cost effective as on date. In case of option 2, the replacement measure is cost effective for discount rates lower than 15% (approx.). This indicates that rebates from utilities can make this a viable option for consumers. In the Option 3, as per the current cost of 5 Star Inverter Split AC, it appears to be a non-viable solution. However, in future when there is a reduction in capital cost (should be market driven), this scheme is expected to be popular owing to reduction in cost of saved energy in comparison to cost of electricity.

Table 1-13 Parameters of various split air conditioners

	2 Star Rated Split AC	3 Star rated Split AC	4 star rated Split AC	5 star rated Inverter Split AC
Cost/unit (Rs)	29120	30353	35512	44750
hours/day	8	8	8	8
days/year	180	180	180	180
Life(years)	10	10	10	10
Cost of power(Rs./kWh)	5	5	5	5
Energy Efficiency Ratio (EER)	3	3.21	3.3	3.94
Capacity (TR)	1.5	1.5	1.5	0.71 - 1.62
Power consumption (Watt)	1740	1640	1550	1444
Annual power consumption (kWh)	2505	2361	2232	2079

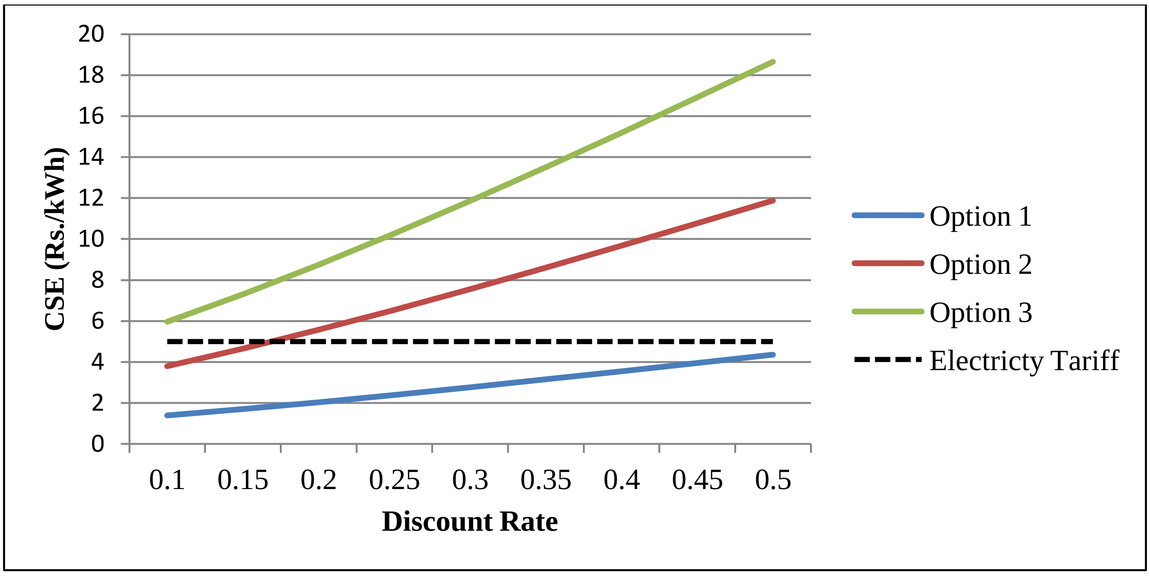

Figure 1-11 Cost of Saved Energy for Various Split AC programs

1.6 Motor Driven Systems

A motor driven system comprises of an electric motor, motor drive or controls, mechanical transmission system and end-use load. The main electricity consuming parts of a motor driven system are electric motor and their control systems (drivers). This motor driving equipment uses mechanical transmission devices such as belts, chains and pulleys to transmit the mechanical power to the driven equipment which is basically the motor load. Compressors, fans, pumps, material processing units (mills, mixers, extruders, crushers, centrifugal machines, etc) and material handling units (conveyors, hoists, elevators, etc) typically represent the end-use motor load in a motor driven system. Figure 1-12 shows the different kinds of motor driven systems used in various load sectors.

The driving equipment in a motor driven system contributes to overall system inefficiency in the form of motor losses. Losses in the motor driven system, especially mechanical losses decrease the shaft power of the motor as well as have significant impact in increase of energy consumption of the system. Adopting a systematic and energy efficient approach will reduce the losses to significant levels.

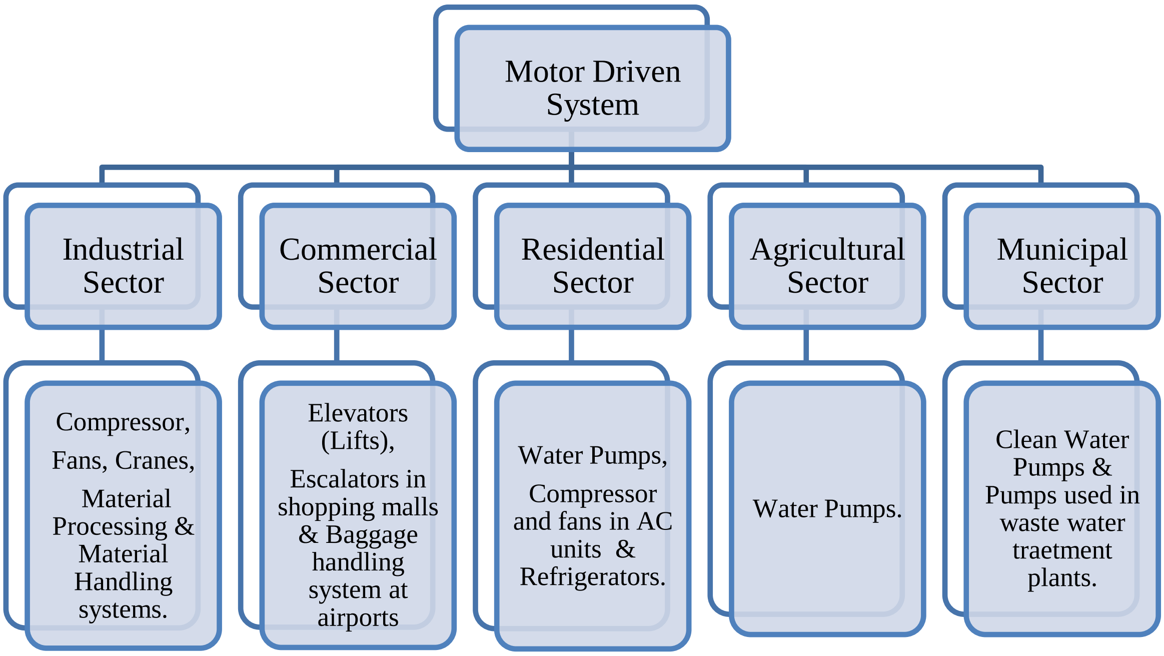

Figure 1-12 Motor driven systems used in different sectors.

Motors and motor driven systems are major consumer of electricity accounting for almost 69% of overall industrial electrical consumption[11]. Their operation (speed and torque) is primarily dependent on the process load and hence this is what governs the amount of electricity consumed by them. Most of these processes have varying demand and therefore some kind of control should be incorporated to meet this varying demand on the load side of the motor. Usually crude control such as throttling, bypass control and on/off control is practiced which are inefficient as they do not meet the precise control requirements and being invasive result in extra installation cost. Considering their high energy consumption, electric motor-driven systems make attractive targets for energy efficiency improvements.

1.6.1 Pumping System - Characterization

Pumping systems account for 25% of industrial motor load. A pump can be defined as a device used to raise, compress, or transfer fluids. These are classified into two types: Positive displacement and Rotodynamic types. These two broad categories of pumps are compared in

---

[11] Energy-Efficiency Policy Opportunities for Electric Motor-Driven Systems, IEA Reporthttp://www.iea.org/publications/freepublications/publication/EE_for_ElectricSystems.pdf

Table 1-14.

1. Rotodynamic Pumps: Rotodynamic pumps (or dynamic pumps) are type of pumps in which kinetic energy is added to the fluid by increasing the flow velocity by using a revolving wheel or rotor or impeller. Typical examples of Rotodynamic pumps include centrifugal pump, turbine pump and submersible pump.
2. Positive displacement pump: These pump causes a fluid to move by trapping a fixed amount of it and forcing (displacing) the trapped volume into the discharge pipe. The rate of fluid flow consequently depends on the speed of rotation. Positive displacement pumps can be further classified into the following types:
    - Rotary Type (Gear Pump, Lobe Pump)
    - Reciprocating Type (Piston Pump, Diaphragm Pump)

Table 1-14 Comparison between Rotodynamic and positive displacement pumps

Rotodynamic Pumps	Positive displacement Pumps
Can run at very high speeds.	Cannot run at high speeds.
Continuous delivery.	Pulsating delivery.
High flow rate.	Low flow rate.
Low pressure developed at discharge.	High pressure developed at discharge.
Suitable for domestic water supply	Suitable for chemical dosing.
Started with discharge valve closed.	Started with discharge valve open.

Figure 1-13 shows a Sankey diagram of a water pumping system where losses in the system are shown proportional to the width of the arrows. This brings to light the various types of losses or sources of inefficiency present in a pump, which is a typical example of a motor driven system. Moreover, these loss points within the system points out the vast energy efficacy potential inherent in a standard pumping system. The energy efficiency measures in context of a water pumping system are dealt in detail in the next section.

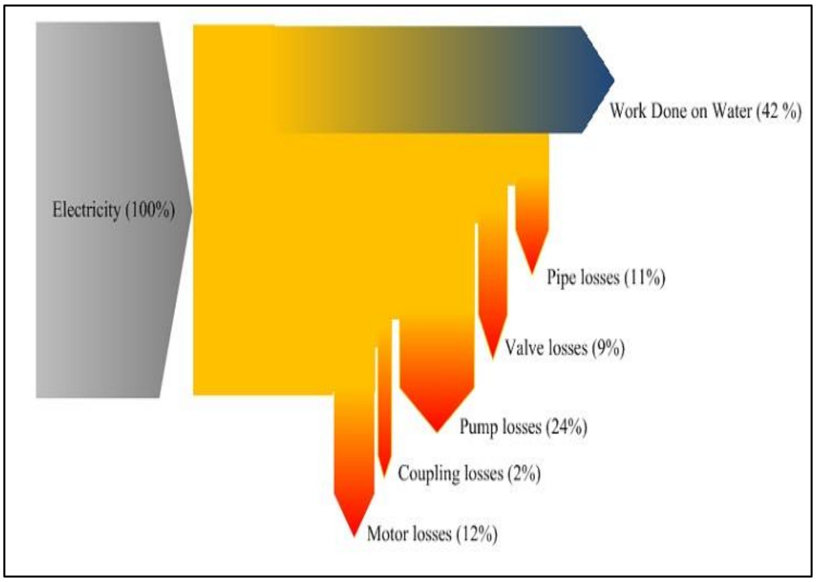

Figure 1-13 Sankey diagram of Water pumping system

1.6.2 Technology Options

The following measures are enumerated and described in context of atypical water pumping system but most of these technologies are common with any motor driven system and can help in mitigating the inherent losses in such systems.

Energy Efficient motors:

Energy-efficient motors also called premium or high efficiency motors are 2 to 8% more efficient than standard motors. Table 1-15 shows the type of losses and the factor affecting these losses in a standard induction motor. Energy efficient motors differ from a standard motors as it counters these factors causing the losses in a way so as to achieve an appreciable improvement in efficiency.

Energy-efficient motors have higher performance characteristics compared to standard motors due to improvement in key design manufacturing features. Energy efficient motor has lengthened core of CRGS steel with thinner stator laminations. Improved bearings, aerodynamic cooling fan further increase efficiency of the system. With longer insulation, lower heat output, energy efficient motors generally have longer life. In addition, these motors tolerate to overload conditions and phase imbalances.

Table 1-15 Losses in a standard induction motor

Type of motor losses	Typical losses (%)	Factors affecting these losses
No Load losses		
Core Losses	15 -25	Type and quantity of magnetic material
Friction and Windage Losses	5-15	Selection and design of fans and bearings
Motor losses under loaded condition		
Stator I2R Losses	25 - 40	Stator conductor size
Rotor I2R Losses	15 - 25	Rotor conductor size
Stray Load Losses	10-20	Manufacturing and design methods

Efficient Coupling system:

A well designed power-transmission coupling system will offer high efficiency, reduced noise levels, needless lubrication, and requires low maintenance. Electric motors in industrial and commercial sector applications use belt drives for power transmission.

Conventional V-belt drives can have a peak efficiency of 95% or more at the time of installation. Currently two most effective belt drives that offer excellent efficiency improvement over standard V belt are described below.

a. **Notched V-Belt:** A notched belt has grooves or notches that run perpendicular to the belt’s length, which reduces the bending resistance of the belt. They run cooler, last longer, and are about 2% more efficient than standard V-belts.

b. **Synchronous Belt:** Synchronous belts (also called cogged, timing, positive-drive, or high-torque drive belts) are toothed and require the installation of mating grooved sprockets. These belts operate with a consistent efficiency of 98% and maintain their efficiency over a wide load range.

Optimum Pump Selection & Sizing:

The operating point of a pump is represented graphically by superimposing pump and system curves. The operating point, as shown in Figure 1-14, is always where these two curves intersect.

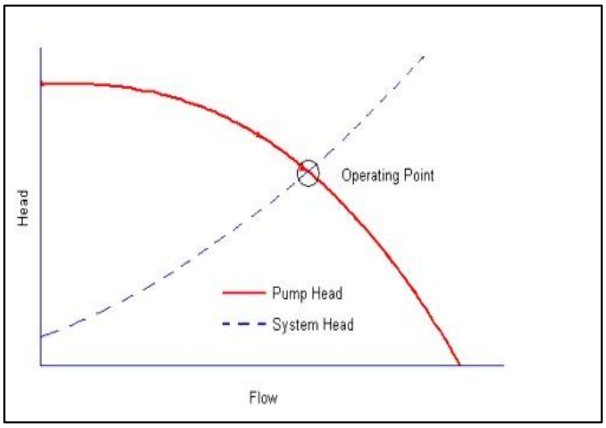

Figure 1-14 Operating point of a pump

An error in the system curve calculation is also likely to lead to selection of a centrifugal pump, which is less than optimal for the actual system head losses. Adding safety margins to the calculated system curve to ensure that a sufficiently large pump is selected generally result in installing an oversized pump, which operates at an excessive flow rate or in a throttled condition, thus increasing energy usage and reducing pump life.

Efficient Flow control mechanism:

A mechanical throttling device is most commonly used to limit flow in the system. This reduces the flow in the system at the cost of wastage in mechanical and electrical energies. The other ways to control the flow in the system are

Variable Speed Drives: Variable Speed Drives (VSD) convert electrical supply of fixed frequency and voltage to **variable frequency and variable voltage.** VSD output is connected to motor input terminals to change its in motor speed and torque to meet the varying load requirements. VSD can be mechanical/hydraulic/electric with the later one being popular. DC drives and AC drives are two types of electrical VSDs. Pumps (variable torque loads) follow affinity laws shown as (6), which states that power consumed (P) is directly proportional to the cube of the speed (N) of operation. That gives almost 12.5% reduction in power consumed for 50% decrease in speed.

$$P_1/P_2 = (N_1/N_2)^3 \qquad (6)$$

This makes it clear that there is a huge potential for energy saving from the use of VSD with centrifugal fans and pumps. For constant torque applications including conveyors, agitators, crushers, surface winders and positive displacement pumps and air compressors, power consumed is directly proportional to speed. This promises less energy savings as compared to that in case of variable torque loads. But still it is worth using a VSD in such applications. In case of constant power applications such as winders and machine tools, there is no energy savings at all as power absorbed is constant for any change in speed. Hence a VSD installation in such cases may yield zero energy saving benefits.

a) **Soft Starters:** Soft starters contain a semi-conductor switch (typically SCR, Silicon Controlled Rectifiers) that cause reduction in the applied voltage by controlling the firing angle of the SCR’s. Soft starters being variable voltage and fixed frequency devices bring about reduction in the current drawn to the motor and hence they cause reduction in power consumption and torque developed during starting and stopping. Moreover, using ZCS (Zero Current Switching) or ZVS (Zero Voltage Switching) techniques, soft starters reduce the power losses that happen on power semiconductor devices due to high frequency switching (Hard Switching) in case of VSD. But soft starter has its share of limitations. The energy saving with the use of soft starters is small thus making the payback period for the investment in soft starters longer. They also tend to introduce harmonics distortions in current which can be mitigated by choosing appropriate filters.

Optimum Pipe Sizing:

The static head of the pumping system has a fixed component and a variable component. The variable component varies linearly with the flow in the system. The power to overcome friction is known as frictional power, depends on flow rate, pipe size (diameter), overall pipe length, pipe characteristics and properties of the fluid being pumped. Correct choice of pipe size along with optimization in piping network can reduce the frictional losses to significant extent.

Case Study – Energy Efficient Pump Sets

Irrigation system needs major policy and technology intervention to make the existing water scavenging irrigation process sustainable. The growing concern in this sector is the decrease in water table depth over the years thus increasing the cost of digging bore wells to tap the ground water. This increase in investment is one of the other reasons that make a farmer buy a less costly substandard pump set. The subsidies in agriculture sector being very high, this initial up-font investment in inefficient pump sets doesn't bother the farmers directly as they are shielded against the increased burden of high operational cost of such pump sets. Use of energy efficient pump sets can help farmers reduce their future investments in terms of time and money in repairing the substandard pump sets that have relatively high maintenance cost. Energy efficient pumps being less energy intensive can help utilities save power from less profitable agricultural sector and increase their revenue by selling this saved power to commercial and industrial customers at a higher cost. Thus, replacement of substandard pumps by their energy efficient star rated counterparts can lead to savings that can benefit both farmers and utilities.

This case study presents the cost-benefit analysis of replacing old substandard irrigation pump sets by their energy efficient options. In order to assess the benefits that will accrue due to replacement of substandard existing pump sets with energy efficient pumps, the cost of saved energy, i.e., the capital invested in order to save one unit of electricity is compared with the cost per unit electricity charged by utilities. If the former happens to be less than the latter, the replacement measure can be considered cost effective.

Majority of irrigation pump sets used in agricultural sector in the country are either submersible type or Monoblock type[12]. The cost of saved energy is calculated for both types and compared with existing electricity tariff to assess the economic viability of these replacement measures. In this case study, the annual cost of saved energy is calculated when an energy efficient technology is replacing existing (conventional) pump set with energy efficient pump set. The cost of saved energy is a statistic used to compare energy conservation measure among them and with the existing cost of energy. An energy-efficient measure is considered to be cost effective when the cost of saved energy is less than cost of electricity. The discount rate represents the scarcity of capital. Higher the discount rate higher

---

[12] Market research of agriculture pump sets industry of India: A report by Shakti Sustainable energy Foundation: June, 2012.
http://www.shaktifoundation.in/cms/uploadedImages/agriculture_pump_study_report_final_12thjune.pdf

is the scarcity of capital or lesser is the availability of funds to invest in energy efficient technology.

The following are the options considered for analysis.
Option 1: Replacement of existing Monoblock pump with energy efficient pump
Option 2: Replacement of existing Submersible pump with energy efficient pump

The details (parameters) of all the four types of pumps are given in Table 1-16 and Table 1-17. The savings associated with choice of energy efficient pumps can easily be assessed calculated from these tables. Based on the time of usage one can calculate the savings in terms of energy. Now-a-days government is encouraging farmers to use energy efficient pump sets for agricultural purpose. In this context, analysis of cost of saved energy for replacement of existing pump sets (Monoblock and submersible) with energy efficient pump sets for various discount rates is done using (1) to (4) and the results are plotted in Figure 1-15. It is clear from the Figure 1-15 that both the options are cost effective.

Table 1-16 Monoblock pump details

	Energy Efficient New pump	**Existing old pumps**
Pump Type	Monoblock (3-Phase)	Monoblock (3-Phase)
Pump Rating (kW)	3.7 (5 HP)	3.7 (5HP)
Discharge Range (Liters per minute)	450-850	450-850
Differential Head Range (Meters)	15-24	15-24
Efficiency	0.50	0.20
Power Requirement (kW)	7	19
Measure Life (Years)	8	8
Usage (Hours/Year)	1200	1200
Retail Market price (Rs.)	25000	0
Annual Electricity use (kWh/Year)	8400	22800

Table 1-17 Submersible pump details

	Energy Efficient New pump	**Existing old pumps**
Pump Type	Submersible (3-Phase)	Submersible (3-Phase)
Pump Rating (kW)	3.7 (5 HP)	3.7 (5HP)

Discharge Range (Liters per minute)	50-130	50-130
Differential Head Range (Meters)	78-162	78-162
Efficiency	0.50	0.20
Power Requirement (kW)	7	19
Measure Life (Years)	8	8
Usage (Hours/Year)	1200	1200
Retail Market price (Rs.)	35000	0
Annual Electricity use (kWh/Year)	8400	22800

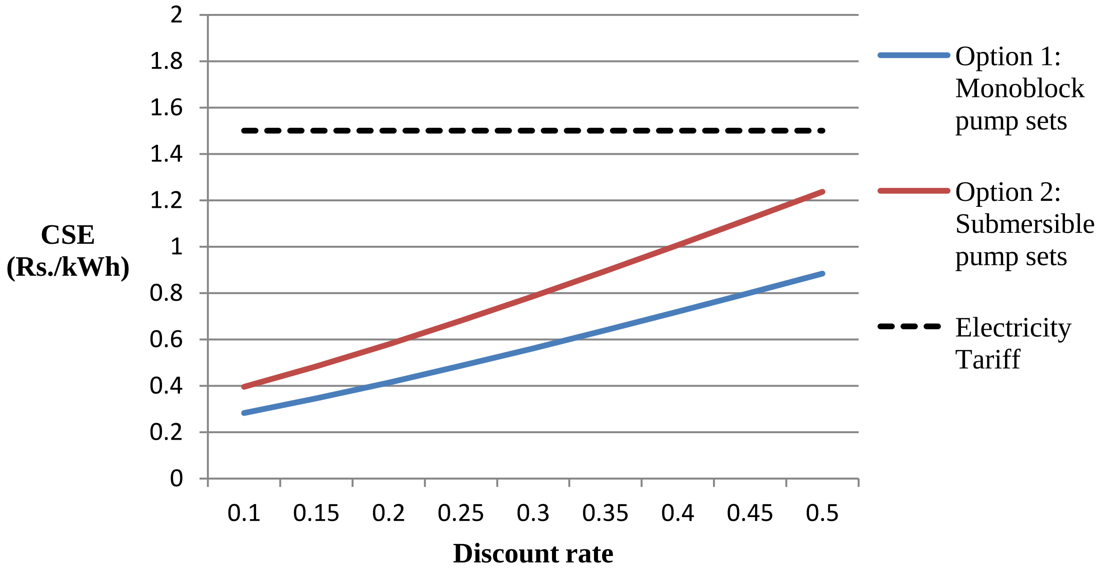

Figure 1-15 Analysis of CSE for pump sets

1.7 Refrigeration

As per Bureau of Energy Efficiency, the 5 star refrigerators are at least 25-40% more efficient than old (non-star) refrigerators. Refrigerator is one appliance which is “ALWAYS ON” thus has its contribution to base load as well peak load. The promotion of 5 star refrigerators would result in significant reduction of peak as well as overall energy consumption. There are two types of refrigerators available in the market.

1. Direct Cool Type
2. Frost Free

The first one is more energy efficient compared to the second one, but the choice of consumers is exactly opposite. The frost free refrigerator consumes more energy for the same capacities because of its automatic defrost mechanism. It is also observed that when utilities implement pilot programs for replacement of old refrigerators with 5 star rated refrigerators, the consumers are inclined to move for double door, frost free refrigerators of higher capacity, which may sometimes result in higher energy consumption.

Case study:

In this case study, the annual cost of saved energy is calculated when an energy efficient technology is replacing existing (conventional) low star rating refrigerator in residential sector. In the present case, replacement options are considered

Option 1: Replacement of non-star rated frost free refrigerator with 5 star rated frost free refrigerator

Option 2: Replacement of 5 star rated frost free with 5 star rated direct cool.

The option 2 is not the choice for the consumers in India as most of them prefer to use a frost free refrigerator. This indicates that a strong message should be delivered to the consumers about the energy inefficiency involved in using a frost free refrigerator at the comfort of one de-frost option.

However, we would like to highlight the importance of direct cool system over frost free and hence the analysis. The cost of saved energy is a statistic used to compare energy conservation measure among them and with the existing cost of energy. An energy-efficient measure is considered to be cost effective when the cost of saved energy is less than cost of electricity. The discount rate represents the scarcity of capital. Higher the discount rate higher is the scarcity of capital or lesser is the availability of funds to invest in energy efficient technology.

Energy efficient options in refrigerators used in residential sector are given in Table 1-18&Table 1-19. The savings associated with choice of star rating can easily be calculated from this table. Analysis of cost of saved energy for replacement of non-star rated frost free refrigerator with 5 star rated frost free refrigerator at various discount rates is done using (1) to (5) and the results are plotted in Figure 1-15.For Option 1, the replacement is a viable option up to discount rate of 27.5% which is usually the case. Interestingly, for option 2, the cost of saved energy comes out to be negative as the energy efficient device is lower in cost when compared to its counterpart.

Table 1-18 Details of Refrigerators for Option 1

	No star Rated	5 Star Rated
Refrigerator type	Frost Free	Frost Free
Storage capacity (Liters)	250	250
Retail Cost/Unit (Rs.)	15000	25000
Annual Energy Consumption (kWh)	1000	364

Table 1-19 Details of Refrigerators for Option 2

	Direct Cool	Frost Free
Star rating	5 Star	5 Star
Storage capacity (Liters)	250	250
Retail Cost/Unit (Rs.)	20000	25000
Annual Energy Consumption (kWh)	274	364

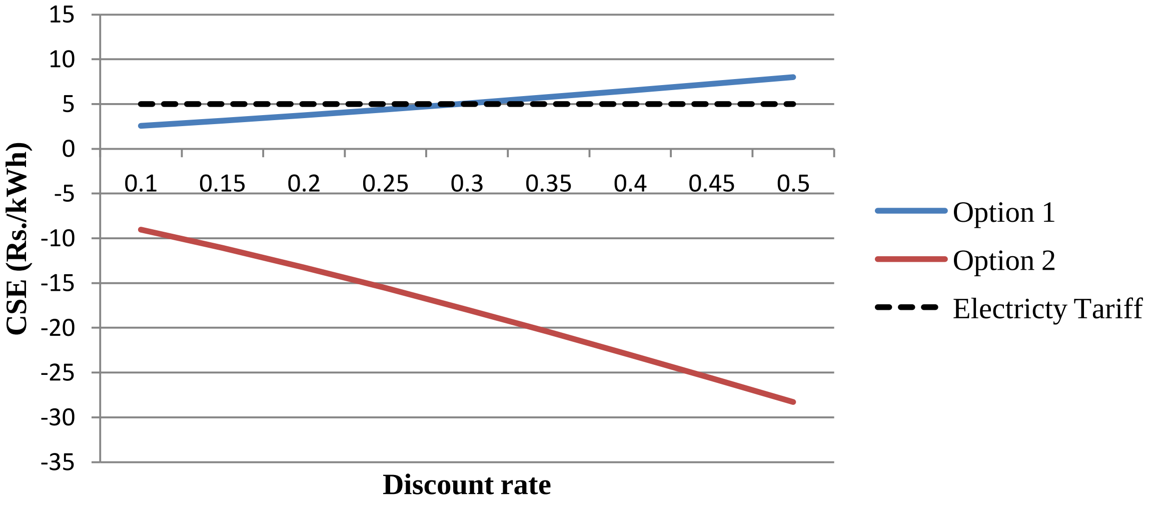

Figure 1-16 Analysis of CSE for refrigerators

1.8 Water Heating

Hot water is used in both domestic households and commercial facilities for a range of jobs like cooking, bathing, washing of clothes, cleaning of utensils, etc. Use of hot water in industrial sector is subject to the type of process involved. Textile, dairy products, pharmaceutical and food industries are some of the industrial facilities that require hot water in quantities much that larger than their domestic and commercial counterparts. Hence choice of water heating technology will differ for various load categories in terms of its ability to fulfil the capacity requirements as well as cost effectiveness. Electric water heaters have a major share in the water heaters market for residential and commercial sector while use of wood, coal and electricity is predominant in boilers for water heating in industries mentioned above. With availability of energy efficient alternatives for water heating in market, there exists a vast potential for energy savings in this end use category that can be tapped to replace the energy intensive electric water heaters. The popular water heating techniques include:

a. Electric Water Heaters
    a. Storage water heaters
    b. Tankless water heater
b. Gas water heater
c. Solar water heater
    a. Evacuated flat plate collector
    b. Vacuum tube type
d. Heat pump water heater

Case study:

In this case study, the annual cost of saved energy is calculated when an electric water heater is replaced with Solar water heaters (with electric heating element as backup). The details of parameters for electric water heater and solar water heater are given in Table 1-20.Analysis of cost of saved energy for replacement of electric water heater with solar water heater for various discount rates is done using (1) to (5) and the results are plotted in Figure 1-17. It is clear that the replacement option is viable for most of the discount rates.

Table 1-20 Comparison of CSE for water heaters

	Electric Water Heaters	Solar Water Heaters (with Electric heating element as back up)
Capacity (Liters)	**2x25=50**	**100**
Cost	**9500x2=19000**	**25000**
Annual Electricity use (kWh/Year)	**800**	**200**

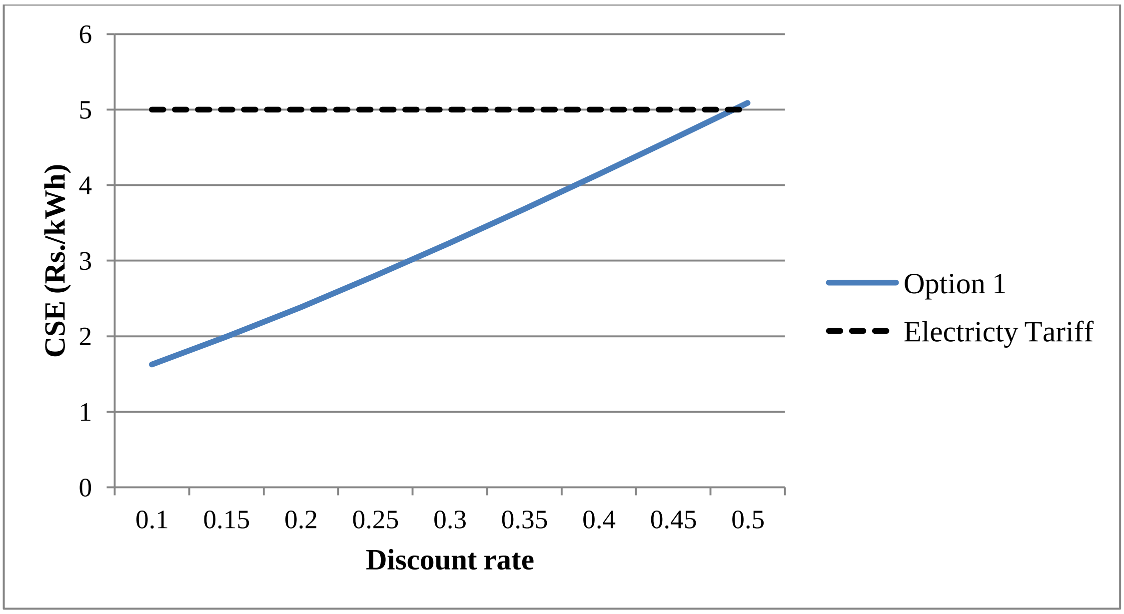

Figure 1-17 Analysis of CSE for water heaters.

1.9 Demand Response

Demand Response is a demand side management mechanism in which the end users of electricity are encouraged to take part in reducing the peak load on the system by altering their normal energy consumption signatures. The end-users in return will be given price or service incentives. Eventually, this process leads to reduction the overall system peak load as end-users shift the operation of some of their loads from peak hours or high market price hours to off-peak hours or low market price hours.

Majority of the DR programs are designed to enhance the reliability of the system and to reduce the energy production from fossil fuel based power plants. Besides improving the reliability, the concept of DR is used to minimize the electricity prices and ancillary service provision in addition to maintaining reliability. It can be used an economic alternative to system expansion.

Figure 1-18 shows list of DR programs available in the literature and these can be broadly grouped into two types as, Incentive based DR and Price based DR programs.

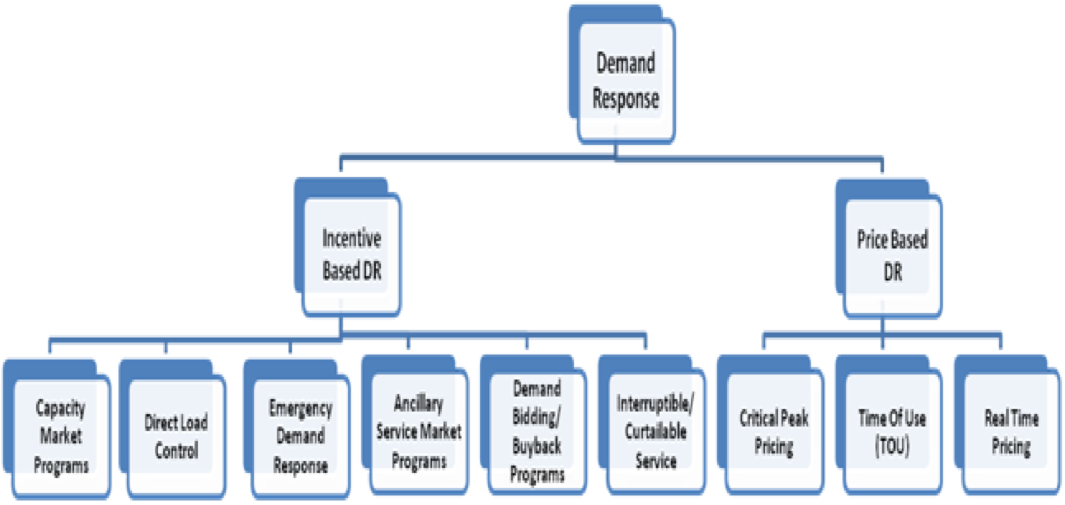

Figure 1-18 General Classification of Demand Response programs

1.9.1. Incentive-based Demand Response:

This category of programs is generally designed by the utilities or regulators, in which contracts are made with customers to increase their participation in demand adjustment during the system peak hours. The contracts specify the type and magnitude of the incentive to be provided to the customers. The incentive can be a price based incentive in which customers will be given the pre-specified amount for the amount of loss reduced as mentioned in the contracts. However, some of these programs also put penalties on the customers for violating the contracts. The following are the methods that fall under incentive based DR programs category.

I. **Direct Load Control:** In this program, the system operators or the program operators such as aggregators operates or curtails or schedules the operation of the customer loads. This is widely suitable for residential customers.

II. **Interruptible/Curtailable (I/C) service:** Under this program, the customers are offered rate discounts or bill credits for their participation in demand adjustment during the scheduled or unscheduled system outages. The customers who have agreed the contract but failed to lower their consumption during the outage hours will be penalised as per the contract norms. The targeted customers for these programs are large industrial loads.

III. **Demand Bidding/Buyback Programs:** In these programs, the customers place their willingness to lower their consumption as bid in the wholesale electricity market. The targeted customers for this category of programs are bulk loads whose consumption is in the order of MW.

IV. **Emergency DR Programs:** In these programs, the customers are incentivised for the reduction of their consumption when the system is in short of reserves.

V. **Capacity Market Programs:** In these programs, the end-users offer load curtailments as system capacity as an alternative to the expansion of the existing infrastructure.

VI. **Ancillary Services Market Programs: Under this program, the large rated c**ustomers place their capacity to lower the consumption as an operating reserve in the form of a bid in the wholesale electricity markets. After succeeding the market process, these customers execute the contracts by lowering their consumption.

1.9.2. Price Based Demand Response:

This is an indirect way of encouraging end-users of electricity to participate in DR programs. Unlike the incentive based DR programs, in this category of DR programs the price of electricity acts as a motivation for the customers to participate in DR. The end-users or customers vary their consumption of electricity in response to the electricity market prices. The prices refer dynamics in the energy availability on the systems, which implies higher electricity prices represents peak hours and lower electricity prices represent off-peak hours. Based on the price differentials, the end-users schedule the operation of their low priority loads. Eventually, the load priority loads of the customers will be shifted to off peak hours and thus, reduces the peak demand on the system and fills the valley portion of the load curve. The following are the DR programs that fall under this category.

I. **Time-Of-Use (TOU):** In this program, the cost of electricity is a function of the time of its use. It proposes a price scheme that has different price slabs for usage during different periods of time. These prices are the average cost of generating the energy in the corresponding duration of the day. In this program, customers may shift some of their loads to off-peak or normal hours to reduce the energy consumption cost.

II. **Real-Time Pricing (RTP):** In this program the will vary for every demand interval based of the supply demand dynamics in the whole sale electricity market and the prices are communicated to the customers or aggregators on day-ahead or hour-ahead basis. These prices act as the basis for voluntary participation of the customers in DR.

III. **Critical Peak Pricing (CPP):** This is a mixed rate scheme of TOP and RTP, in which the price has three slabs. However, the price during the peak hours is subjected to market dynamics.

1.9.3. Demand Response Strategy for Residential and Commercial Sector[13]

The low priority loads of residential and commercial sector can be classified into two categories, namely shift-able loads and curtail-able loads.

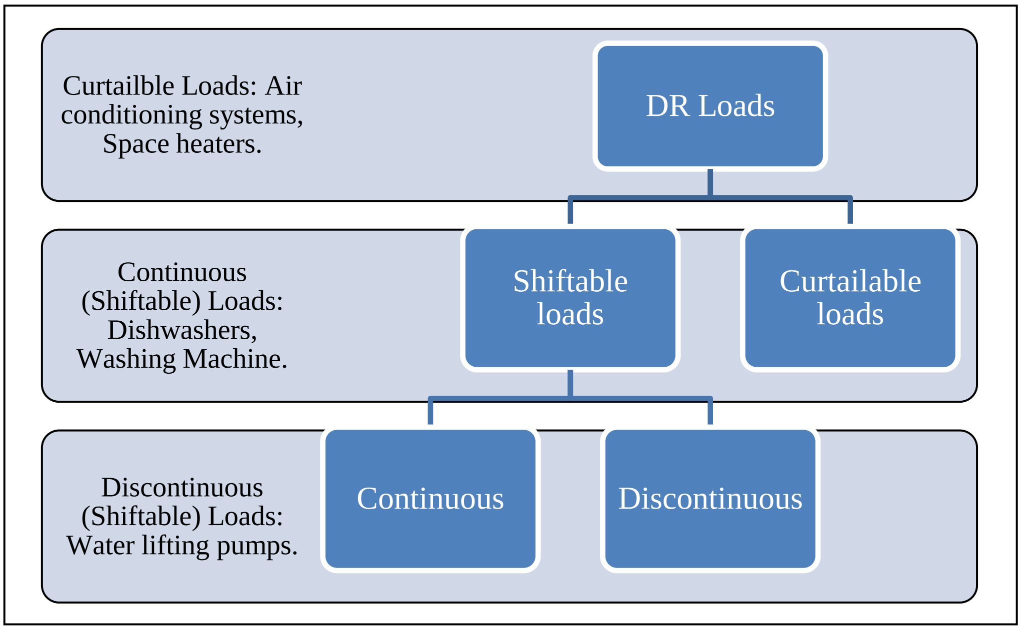

Figure 1-19 Classification of load that participate in Demand Response programs

Demand Response participations options, as shown in Figure 1-19, are required for assisting customers to participate in demand side management. For example,

- **Continuous Shift-able DR option:** Under this option, the low preference appliances that require electricity for the specified number of consecutive intervals (E.g., Washing Machine, Dish washers) shall enroll for DR participation.

---

[13] Intelligent demand response approach in smart distribution systems: A review.
Authors: A.M. Saklani, H.S.V.S. Kumar Nunna and S. Doolla.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6420773

- **Discontinuous Shift-able DR option:** Under this option, the low priority appliances which do not require uninterrupted supply of electricity for completing their job (E.g., Water lifting pumps) shall enroll for DR participation.
- **Curtail-able DR option:** This option is suitable for the customers having low preference loads such as air conditioners and space heaters which can be curtailed when electricity prices are higher. These loads are curtailed under power deficit situations and operate the load if power is excess.

1.9.4. Demand Response Strategy for Industrial Sector

Developing demand response programs for industries pose few big challenges. Industries have processes that are unique to the type of industry and produce an end product using a set of processes occurring in an order. For designing a DR program for Industrial load require identification of a set of processes that have the flexibility to be curtailed or shifted using the DR strategies explained in the previous section. Report on "Implementation of demand response program in Tamil Nadu[14] " by Mercados Energy Markets India Pvt. Ltd., details the strategies that can be employed to implement DR programs for industries where technical and economic potential for DR exists.

Case Study

The Tata Power Demand Response is a manual DR program which works on aggregator based model. It works totally on consumer participation where end-user sheds the load on utility requests and is given payment for that on the units (kWh) basis. In 2012, Tata Power carried out several DR events. There were voluntary curtailments for 100 hours during the year. The load curtailments were invited when the power purchase cost is high or during the system contingencies. The consumers are benefitted from the reduced purchase of the power during peak hours and the same is reflected on their monthly bills. The service provider in this case study offered up to Rs. 2.25 per kWh of reduced electrical energy relying on the reference line developed using "4 out of 5 similar days" methodology.

The load curtailment is done with help from DR aggregators that bundles loads of all the end-users and provides large load reduction on the utility. The service provider enrolled the end-users who can shed the load (greater than or equal to 50 KW) for duration of 2 hours

---

[14] Report on "Implementation of Demand Response program in Tamil Nadu."
http://www.shaktifoundation.in/cms/uploadedImages/implementation%20of%20demand%20response%20program%20in%20tn.pdf

on request. Tata Power enrolled a capacity of 10MW load under this demand response program and incentives were then provided to participating customers based on the quantum of load reduction achieved.

1.10 Combined Heat and Power Systems

Cogeneration is a mechanism of sequential or simultaneous generation of more than one form of energy (mostly thermal and mechanical) in a single integrated system. Cogeneration or Combined Heat and Power (CHP) systems, also referred as total energy systems provide a reliable and efficient way to generate electric power and heat using a single fuel.

CHP can be viewed as a distributed generation (DG), which is at a strategic location near customer facilities to supply localized energy needs. CHP plays dual roles by simultaneous production of useful thermal and power output, thereby increasing overall efficiency

The primary individual components of a CHP system contain:

- Prime mover which is basically a heat engine that convert the caloric value of fuel to mechanical power,
- Generator that converts mechanical power to electrical power, and
- Waste Heat recovery unit that taps the unused or waste thermal energy in flue gases from a DG, or in steam from cooling towers or even in waste water from cooling processes so as to preheat the feed fluid in CHP system.

The parameters that decide whether a cogeneration system is technically and economically viable for a facility viz.:

- Technical Feasibility:
    - Heat to Power ratio: It is the ratio of the heat or thermal energy generated to the amount of power generated on the basis of same unit of energy. It plays a central role in the choice of appropriate CHP technology based on the end user application.
- Economical Viability
    - Relative fuel Savings (R_f): It denotes the fuel savings accrued due to CHP system over separate heat & power generation.
    - Fuel Chargeable to Power (FCP): It is the incremental fuel in cogeneration that is used for the power generation.

Estimation of electrical and thermal load profile of the facility through utility bills and anecdotal information about the functioning of the site along with power to heat ratio are used to identify the applicability of various types of prime movers for the proposed CHP system. The following are the few notable merits of cogeneration plant that provide the rationale for CHP technologies in the present context.

- CHP uses fossil fuels more efficiently, saving between 20% and 40% over stand-alone systems. In addition, CHP reduces energy costs by eliminating or deferring costly transmission and distribution infrastructure investments.
- CHP improves the reliability and security of energy supply by using local fuels and waste products as inputs.
- CHP improves air quality, reduces the environmental impacts of energy use and produces less air pollutants than standalone alternatives.

1.10.1 Available Cogeneration Technologies

Figure 1-20provides a detailed classification of commercially available CHP technologies that are in practice all over the globe.

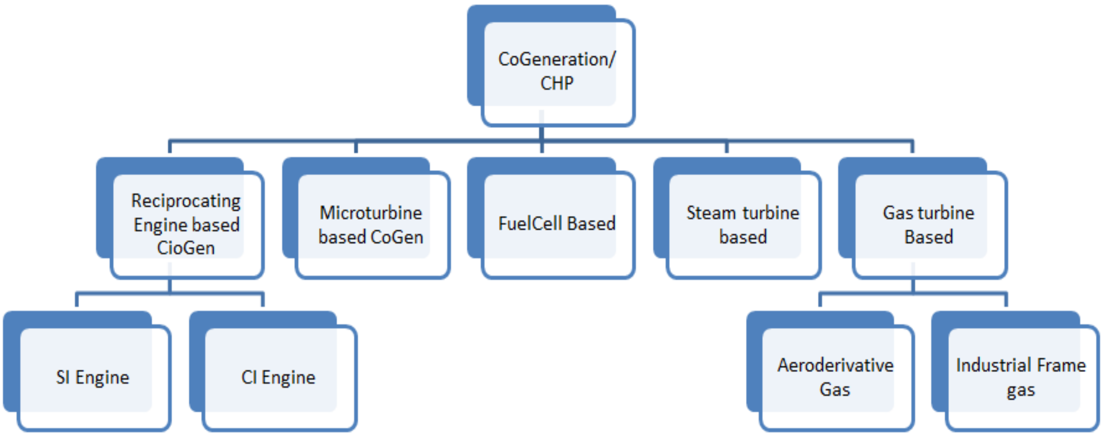

Figure 1-20 Technology options for CHP systems based on the type of prime mover or heat engine used

Steam Turbine based cogeneration system:

Steam Turbine based cogeneration system employs steam turbine as a prime mover to drive a generator for power generation. Industries or facilities having demand profile for heat and power with high heat to power ratio are best suited to employ steam turbine based cogeneration system.

Figure 1-21depicts the primary components of a typical Steam turbine based CHP system. Steam turbine works on the Rankine cycle model. In rankine cycle, water is pumped to elevated pressure and heated in boiler to generate high pressure steam. The pressurized steam is passed through a turbine (can be multistage) for expansion to lower pressure, the exhausted steam is condensed by a condenser. The condensate from the condenser is returned to the feed water pump for continuation of the process.

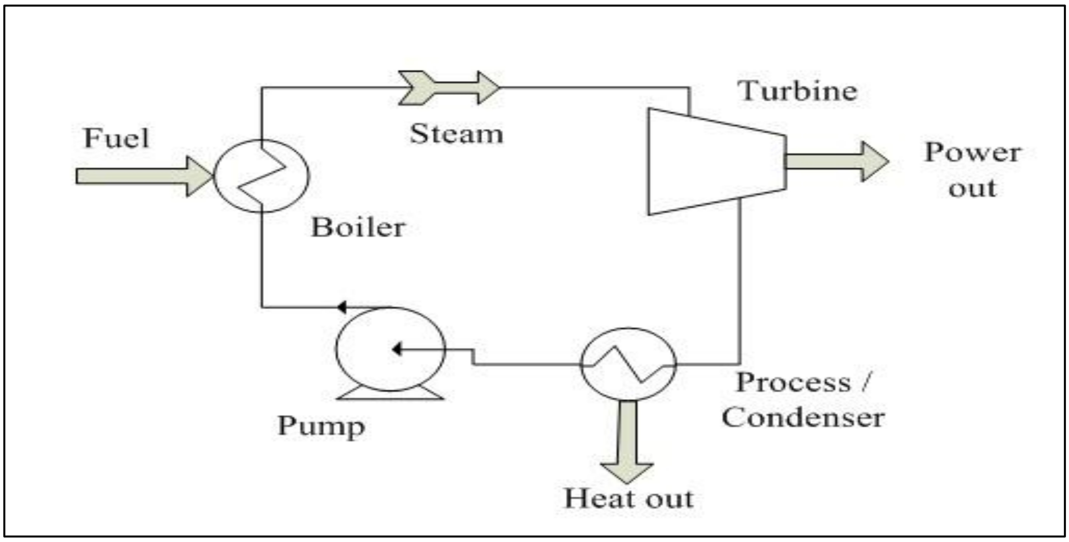

Figure 1-21 Components of Steam turbine based CHP system

Steam turbines completely differ from reciprocating engines and gas turbines, in the later fuel were burnt in the equipment to generate the energy but in the earlier, fuel is burnt at the boiler, and energy is transferred from the boiler to the turbine by high pressure steam.

Types of Steam Turbines:

There are two types of steam turbines used for CHP applications namely Back pressure turbine and extraction turbine.

a. Non-condensing (Back Pressure) steam turbine

Ina non-condensing type turbine (back-pressure turbine), entire flow of steam is exhausted to the industrial process heat at exit conditions of steam close to the process heat requirements, as show in Figure 1-22(a). The discharge pressure is decided by the specification of the CHP application.

b. Extraction Turbine

Extraction turbine has opening(s) in its casing for extraction of a portion of the steam at some intermediate pressure. The steam extracted from the openings can be used for any process in the facility of can be used for feed water heating purpose. The remaining steam exhausted can be condensed, as shown in Figure 1-22 (b). Openings are provided based on the steam requirements of the utility.

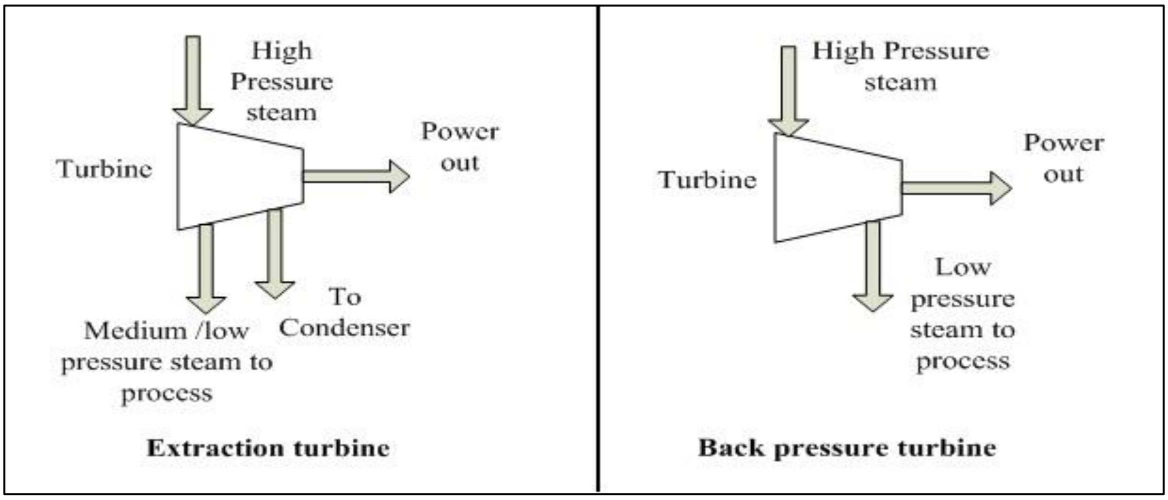

Figure 1-22: (a) Extraction steam turbine (b) Back pressure steam turbine

Performance and efficiency enhancement measures for Steam turbine based CHP systems

Steam Reheat

Power extracted from unit mass flow of steam is dependent on pressure ratio and steam inlet temperature conditions.High pressure ratio and inlet temperature yield more power provided they are in the operation limits of the turbine.

When steam attains the practical limit of temperature in the boiler, it is expanded to an intermediate pressure in a turbine. Steam is once again heated to the upper temperature limit and expanded in a low pressure turbine. This process increases the efficiency of the total CHP system.

Combustion Air Preheating

In large industrial systems, air pre-heatersare employed to recover waste heat from the boiler exhaust gas stream.This recovered waste heat is used to preheat the feed water of the boiler, thereby reducing fuel consumption of it.

1.10.2 Technology Comparison matrix

The metrics used to compare and hence assess the various cogeneration technologies in Table 1-21 are in no way exhaustive and it should always be complemented by practical needs of the facility where CHP plants is to be installed.

Table 1-21 Technology comparison Matrix for CHP/ Cogeneration

CHP /Cogeneration
Technology Comparison Matrix[15]

Metrics for comparison	Steam Turbine	Gas Turbine	Reciprocating Engine	Micro Turbine	Fuel Cell
Typical Capacity (MW)	0.05 - 250	0.5 - 250	< 5	0.03 – 0.25	0.005 - 2
Power efficiency	15 - 38	22 - 36	22- 40	18 - 27	30 - 63
Overall efficiency	80	70 - 75	70 - 80	65 - 75	55 - 80
Effective electrical efficiency (%)	75	50 - 70	70 - 80	50- 70	55- 80
Typical Power to Heat ratio	0.1 – 0.3	0.5 - 2	0.5 - 1	0.4 – 0.7	1- 2
Start-up time	1 hr-1 day	10 min-1hr	10 sec	1 min	3hrs-2days
Fuels used	all	Natural gas, Biogas, Propane, & oil	Natural gas, Biogas, Propane, & Landfill gas	Natural gas, Biogas, Propane, & oil	Hydrogen, Natural gas, Propane, Methanol
Noise level	High	Moderate	High	Moderate	Low
Power Density (kW/m^2)	>100	20-500	35-50	5-70	5-20
Advantages	High overall efficiency. Fuel flexibility. Ability to meet more than one site heat grade requirement. Long working life. High Reliability. Variable Power to heat ratio. .	High reliability. Low emissions. High grade heat available. No cooling required.	High power efficiency with part load operational flexibility. Fast start-up. Relatively low investment cost. Can be used in island mode and have good load following capability. Operates on low pressure gas.	Small number of moving parts. Compact size and light weight. Low emissions. No cooling required	Low emissions and low noise. High efficiency over load range. Modular design.

---

[15] Catalogue of CHP technologies : EPA
http://www.epa.gov/chp/technologies.html

Disadvantages	Slow start up. Low power to heat ratio.	Requires high pressure gas or in house gas compressor. Poor efficiency at low loading. Output falls as ambient temperature rises.	High maintenance costs. Limited to lower temperature Cogeneration applications. Relatively high air emissions. Must be cooled even if recovered heat is not used. High levels of low frequency noise.	High costs. Relatively low mechanical efficiency. Limited to lower temperature Cogeneration applications.	High costs. Low durability and power density. Fuel requires processing unless pure hydrogen is used.

Case Study:

A simple case study of steam turbine based combined heat and power generation is given. It is assumed that non-condensing turbine is used to drive a generator that reduces high pressure superheated steam to lower pressure saturated steam. This lower pressure steam is used for heating water and is condensed at 212^0F. The lower pressure steam can also be used for other industrial purposes depending upon the type of industry. The following is the input data for analysis

Inlet steam pressure: 615 psi (absolute)
Inlet steam temperature: 752^0F
Outlet steam pressure: 75 psi (absolute)
Outlet steam temperature: 307^0F
Steam flow rate (measured),F_S = 7289 lb/hr,
Exhaust condensate flow rate (measured),F_{CO} = 218 lb/hr
Unit steam cost, C_S: Rs. 1/lb,
Unit electricity cost, C_E: Rs.5/kWh,
Operation time, t: 8400 hr/yr
Turbine nameplate shaft power output, W_T: 340 kW
Turbine nameplate steam rate, F_T: 22 lb/kWh
Generator Efficiency, E_G= 92%,
Generator power output (measured): 309kW

Objective is to compute turbine efficiency, steam cost attributable to steam turbine, value of electricity generated and energy cost savings.

Solution:
Shaft power input to generator $= \frac{309}{0.02}$ = 336 kW

If we neglect the loss in the coupling, then turbine shaft output power, W_{TO} = 336 kW

Ideal Steam Rate (ISR) is the quantity of steam that will produce a unit of shaft energy output from an ideal steam turbine having no machinery or thermal loss. By using Mollier diagram ISR is calculated:

H_I = 1378 Btu/lb, H_O = 1182 Btu/lb

Therefore, ISR (lb/kWh) = 3413 / (H_I– H_O)

Where H_I: enthalpy of inlet steam (Btu/lb), H_O: enthalpy of outlet steam (Btu/lb), 3413 is the conversion constant for Btu to kWh scale.

ISR=3413/ (1378 – 1182) = 3413/196 = 17.4 lb/kWh

Actual steam rate (ASR) is the flow of steam required to produce a particular shaft power output.

ASR =F_S/W_{TO} = 7289/336 = 21.7 lb/kWh

(Compared with the nameplate steam rate of 22 lb/kWh)

Overall steam turbine efficiency = ISR/ASR = 17.4/21.7 x 100 = 80%

$Q_T = F_S$ x (H_I – H_R) = 7289 x (1378 – 180) = 8.73 x 106 Btu/hr

(H_R: the H_F column for 212^{O}F condensate from steam table)

Energy extracted by the steam turbine

Q_E= (F_S x H_I) – (F_{CO} x H_{FO}) – ((F_S – F_{CO}) x H_{GO})

(H_{FO}& H_{GO} from steam table and the H_F and H_G column for 307^{O}F steam)

H_{FO} = 277 Btu/lb, H_{GO} = 1182 Btu/lb

Q_E= (7289 x 1378) – (218 x 277) – ((7289 – 218) x 1182) = 1.63 x 106 Btu/hr

Steam flow rate attributed to turbine: $F_{ST} = F_S$ x Q_E/Q_T= 7289 x 1.63/8.73 = 1361 lb/hr

Annual steam cost of steam turbine = F_{ST} x t x C_S = 1361 x 8400 x 1= Rs.11432400/yr

Annual value of electricity = W_{GO} x C_E x t = 309 x 5 x 8400 = Rs. 12978000/yr

Annual energy cost savings = Rs. (12978000 - 11432400) / yr = Rs.1545600/yr